EVALUATION OF EFFECTS OF CASTING AND CURING CONDITIONS AND SPECIMEN TYPE ON CONCRETE STRENGTH AND PERMEABILITY

By
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A Report on Research Sponsored by

The Kansas Department of Transportation

K-TRAN Project KU-12-1

Structural Engineering and Engineering Materials
SM Report No. 119
January 2017

THE UNIVERSITY OF KANSAS CENTER FOR RESEARCH, INC.
2385 Irving Hill Road, Lawrence, Kansas 66045-7563

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PREFACE

The Kansas Department of Transportation's (KDOT) Kansas Transportation Research and New-Developments (K-TRAN) Research Program funded this research project. It is an ongoing, cooperative and comprehensive research program addressing transportation needs of the state of Kansas utilizing academic and research resources from KDOT, Kansas State University, and the University of Kansas. Transportation professionals in KDOT and the universities jointly develop the projects included in the research program.

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ABSTRACT

Time and curing conditions may impact the strength and permeability of concrete. The strength and permeability of concrete with and without supplementary cementitious materials (SCMs) were evaluated as a function of specimen type, season during which construction occurred, and age. Three concrete mixtures were included in the study, a control mixture with 100% portland cement, a mixture with 35% replacement (by weight) of cement with slag cement, and a mixture with 25% replacement with slag and 15% replacement with fly ash. Pavement slabs containing each mixture were cast in the summer, fall, and spring, along with companion 4 × 8 in. cylinders, to determine the effect of seasonal variations in environmental conditions on the strength and permeability of concrete. Cylinders were cured in both the laboratory and the field, and cores were taken from each slab. Specimens were evaluated for compressive strength, void content using the boil test, and ionic conductivity using the rapid chloride permeability (RCP) test at ages of 28, 56, 90, 180, 360, and 720 days. Additional laboratory tests were performed to evaluate the correlation between diffusion coefficient obtained from ponding tests and void content, and ionic conductivity. The study demonstrated that cores and field-cured cylinders have lower compressive strength and greater permeability than lab-cured cylinders. Concrete cast during either hot or cold weather tends to exhibit lower strength and greater permeability than concrete cast closer to 70 °F; mixtures containing fly ash tend to be more affected by lower temperature at early ages. The use of SCMs, however, mitigates some of the effects of hot weather. The results of the boil test do not correlate well with diffusion coefficient or ionic conductivity.

KEYWORDS: Compressive strength, concrete, durability, permeability, supplementary cementitious materials

ACKNOWLEDGEMENTS

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This project would not have been possible without the work of graduate students Jiqiu Yuan, Scott Storm, James Lafikes, and Isaac Somogie, as well as several undergraduate assistants. Their contributions are greatly appreciated.

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CHAPTER 1: INTRODUCTION

1.1 Problem Statement

Questions have arisen in practice about the rate at which concrete systems gain strength over time and the relationship between test results from concrete cast in the field and those derived from cylinder tests. The gain in strength for concrete mixtures with and without supplementary cementitious materials and the related impact of time and curing conditions on the permeability of these mixtures are also of interest.

Concrete gains strength at different rates depending on the curing conditions and mixture constituents. The durability of concrete, as measured by its relative permeability, is also affected by the degree of hydration of the concrete mixture. The moisture available to support the hydration process and the temperature of the concrete at placement and during curing are key factors that influence the strength and permeability of the concrete over time. In addition, some combinations of supplementary cementitious materials (SCMs) and portland cement react more slowly than portland cement alone and, therefore, require different curing conditions to achieve similar strength and permeability as concrete that contains only portland cement. A summary of prior research on the effect of SCMs is provided below.

1.2 Overview of SCMs

In this study, the partial replacement of cement by slag cement and Class C fly ash are investigated. Generally, slag cement, fly ash, or both are used as replacements for portland cement when it is desirable to reduce the heat of hydration or to improve the durability of concrete. This section provides a short overview of these mineral admixtures and how they affect plastic and hardened concrete properties.

1.2.1 Slag Cement

Slag cement is the granular material that is formed when molten iron blast furnace slag is rapidly cooled by water. This granular product with limited crystal formulation is highly cementitious and will hydrate like portland cement when ground to cement fineness. Slag cement is governed by ASTM C989. There are three strength grades of slag cement, 80, 100, and 120 (ASTM C989). The compressive strength of concrete containing Grade 80 slag cement will be significantly lower than a mixture containing 100% portland cement (PC). Therefore, the Federal Highway Administration (FHWA 2011) advises that Grade 80 slag cement should only be used in mass concrete applications where the heat of hydration is of particular concern. Slag cement may be substituted for cement on a 1:1 weight basis, but it is recommended that the substitution be limited to 50 percent where the concrete will not be exposed to deicing salts and 25 percent where the concrete will be exposed to deicing salts (FHWA 2011).

1.2.1.1 Effects of Slag Cement on Plastic Concrete Properties

Workability: The use of slag cement as a replacement of portland cement on an equal weight basis, in general, increases the workability of plastic concrete and decreases the water demand. This is due in part to the increase in paste volume that is caused by the lower relative density of the slag cement as well as the surface characteristics of the slag cement particles, which create smooth slip planes in the paste (ACI Committee 226 1987a).

Setting Time: In general, the setting time of concretes containing slag cement increases with increasing slag contents. The FHWA (2011) reports that an increase of slag cement content from 35 to 65% can extend the setting time by as much as one hour. ACI Committee 226 (1987a) reports that setting time is also affected by the initial curing temperature of the concrete, the water-to-cementitious material (*w/cm*) ratio, and the characteristics of the portland cement. Little difference in setting time between regular portland cement concrete and portland cement-slag cement concrete is seen when the temperature is above 85°F.

Bleeding: With the addition of slag cement to concrete, the rate of bleeding and quantity of bleed water is reduced because of the higher fineness of the slag cement particles. If the slag cement is coarser than portland cement, however, the rate and amount of bleeding may increase (ACI Committee 226 1987a).

Air Entrainment: Because of the higher fineness of the slag cement, the amount of air entraining admixture may need to be increased. However, the stability of the air bubbles and air loss are not affected by the addition of slag cement.

1.2.1.2 Effects of Slag Cement on Properties of Hardened Concrete

Compressive Strength: The compressive strength development of concretes containing slag cement depends on the type, fineness, activity index, and proportions of slag cement used in the concrete mixtures (FHWA 2011). In general, Grades 100 and 120 slag cement will cause the initial strength gain to be slow (from 1 to 5 days), but between 7 and 28 days, the strength approaches that of similar concrete made with only portland cement, and after 28 days, the strength of concrete containing slag cement exceeds that of portland cement-only concrete. In cold weather, however, the rate of strength gain may be substantially reduced [up to 14 days (FHWA 2011)]. Concrete made with Grade 80 slag cement generally never reaches the same strength as concrete made with only portland cement.

Permeability; Concretes containing slag cement usually have decreased permeability due smaller pores in the paste. The pore structure of the cementitious matrix is changed through the reaction of slag cement with the calcium hydroxide and alkalis released during the hydration of the portland cement (ACI Committee 226 1987a).

Freeze-Thaw Durability: Freeze-thaw durability tests of concrete containing slag cement indicate little difference in the durability of concrete with and without slag cement (ACI Committee 226 1987a). As with all concrete, proper air entrainment and bubble spacing are necessary for freeze-thaw durability.

Alkali-Silica Reaction: Using slag cement as a partial replacement for portland cement is known to reduce the potential expansion of concrete due to the alkali-silica reaction. This reduction is attributed mainly to the reduction of total alkalis in the cement-slag blend, the lower permeability of the concrete, and binding of the alkalis released in the hydration process (Mindess, Young, and Darwin 2003, FHWA 2011).

Corrosion of Reinforcing Steel: The lower permeability of concrete containing slag cement reduces the penetration of chlorides and oxygen, which promote the corrosion of reinforcing steel. Although the pH of the pore solution is reduced when slag cement is added, the reduction is balanced by the reduced permeability.

Curing: Care should be taken to ensure proper curing of concrete containing slag cement. Due to the increased time of set and the reduced initial rate of strength gain, concrete containing slag cement is more susceptible to cracking caused by drying shrinkage if not adequately cured. Additionally, the degree of set retardation is temperature sensitive and may become more pronounced at lower temperatures.

1.2.2 Fly Ash

Fly ash is "the finely divided residue resulting from the combustion of ground or powdered coal which is transported from the firebox through the boiler by flue gases" (ACI Committee 226 1987b). Fly ash has pozzolanic properties, which allow it to be used as a partial replacement for portland cement. The glassy silica found in fly ash chemically reacts with the calcium hydroxide formed during the hydration of portland cement to form compounds that possess cementitious properties. ASTM C618 specifies two classes of fly ash—Class F and Class C. Class F fly ash is typically produced by burning anthracite or bituminous coal. Class C fly ash is typically produced by burning sub-bituminous coal or lignite. Class F fly ash has pozzolanic properties but does not have any cementitious properties, whereas Class C fly ash has pozzolanic and some cementitious properties.

1.2.2.1 Effects of Fly Ash on Plastic Concrete Properties

Workability: The use of fly ash generally improves the workability of fresh concrete and decreases the water required for a given slump. This is due to the fineness and roundness of the fly ash particles, as well as the lower relative density of the particles, which increases the paste volume.

Setting Time: Like slag cement, fly ash tends to retard the time of setting. However, according to ACI Committee 226 (1987b), Class C fly ash may extend, reduce, or have no significant effect on the time of setting. The setting time will depend on ambient and concrete temperatures with higher temperatures leading to a decreased time of set. Setting time also depends on cement type and content, water content of the paste, soluble alkalis, the use of other admixtures, the amount of fly ash, and the fineness and chemical composition of the fly ash (ACI Committee 226 1987b).

Bleeding: Due to the greater volume of fines and lower water content for a given slump, the rate of bleeding and the amount of bleed water is reduced when fly ash is used. The added fines from the fly ash may also compensate for any lack of fine material in aggregate.

Air Entrainment: The use of fly ash will, in general, require an increase in the amount of air-entraining admixture. Air loss is dependent on the properties of the fly ash. For example, if the fly ash contains significant water-soluble alkalis, the amount of air-entraining admixture may need to be reduced rather than increased. Some research suggests that the more the mix is agitated, the greater the reduction in air content and spacing of air voids (ACI Committee 226 1987b).

1.2.2.2 Effects of Fly Ash on Properties of Hardened Concrete

Compressive Strength: The use of fly ash will typically result in lower early strength when compared to a comparable cement-only concrete. This slower early strength gain does not typically affect the 28-day strength. Concrete containing fly ash that has lower or equivalent strength at early ages will, most likely, have equivalent or higher strength at later ages than concrete without fly ash. This higher rate of strength gain at later ages, due to the pozzolanic reaction of the silica in fly ash with $Ca(OH)_2$ produced by cement hydration, will continue and will result in higher later strengths than can be achieved by using additional cement. The strength of concrete that contains fly ash is, however, highly dependent upon adequate curing because water must be available for the pozzolanic reaction to proceed.

Permeability: Concrete permeability is affected by many variables, including the amount of cementitious material, water content, aggregate gradation, consolidation, and curing conditions. Fly ash reduces the permeability of concrete due to its pozzolanic properties. Fly ash chemically combines with calcium hydroxide to form additional calcium silicate hydrate (C-S-H, the main product of the hydration of cement), which reduces the risk of calcium hydroxide leaching out of the concrete and, thus, reduces the permeability. Calcium hydroxide, which is liberated by the hydration of cement, is water soluble. When calcium hydroxide is allowed to leach out of the hardened concrete, it will leave voids that allow for the ingress of water.

Freeze-Thaw Durability: There has been little difference in freeze-thaw durability between concretes with and without fly ash. The freeze-thaw durability of concrete with both fly ash and cement and concrete with cement only is dependent on the adequacy of the air-void system, the soundness of the aggregates, age, degree of hydration, strength of the paste, and moisture condition of the concrete (ACI Committee 226 1987b).

Alkali-Silica Reaction: The addition of fly ash will, in general, reduce the risk of the alkali-silica reaction. This is due to (1) the reduction of the portland cement content due to the partial replacement with fly ash, (2) the reduced pH of the pore solution relative to portland cement-only concrete, and (3) the increase in solubility of calcium (Mindess, Young, and Darwin 2003). This increase in soluble calcium results in the formation of a nonexpanding calcium-alkali-silicate gel C-N(K)-S-H instead of the swelling alkali-silicate gel N(K)-S-H. When using Class C fly ash, a 35–40% replacement for portland cement is usually needed to be effective in reducing the alkali-silica reaction. The reason for this is due to the high lime content of Class C fly ash, lowering the amount of silica available to control the alkali-silica reaction. Class F fly ash is more effective in controlling the alkali-silica reaction and only requires approximately 15–20% replacement of cement.

Corrosion of Reinforcing Steel: There has been concern that the addition of fly ash will reduce the pH of concrete due to its acidic oxide content, thus affecting the passivity of the steel. However, researchers have found that the pH of concrete containing fly ash will remain sufficiently high to preserve the passive layer on the steel (ACI Committee 226 1987b). In addition, the reduced permeability of the concrete will decrease the rate of ingress of water, corrosive chemicals, and oxygen, thus reducing the negative effects of the reduced pH of the paste.

Curing: As stated earlier, it is important to ensure proper curing to achieve adequate strength gain for concretes containing fly ash. The strength gain is due to the pozzolanic reaction of fly ash, which requires water, water that will not be present without proper curing. Also, the longer setting time caused by the addition of fly ash increases the potential for plastic shrinkage cracking, which can be reduced by minimizing evaporation from the concrete surface and early initiation of curing.

1.3 Previous Work

It is well established that there are differences in the properties of in-situ concrete and concrete cylinders. Many factors contribute to these variations, such as placement procedures, curing conditions, the effect of bleed water migration during concrete placement (especially in deep members), and the extra compaction of the concrete near the bottom of deep members due to the weight of the concrete above. In most cases, this will result in a compressive strength as determined from concrete cylinders slightly higher than that of the in-situ concrete. According to MacGregor (1976), the mean 28-day strength of concrete in a structure cured with minimum acceptable curing can be taken as $\bar{f}_{c(\text{structure})} = (0.675 f_c' + 1.1)$ ksi, where f_c' = 28-day cylinder strength.

The difference between concrete cylinder properties and the properties of in-situ concrete is especially evident in concrete pavements due to the large surface area-to-volume ratio of pavements. Thus, it is important to understand the behavior of concrete as a function of curing conditions and duration. This section gives a brief overview of one study comparing the strength of concrete cylinders with in-situ concrete strength and two studies on the effects of curing conditions on the properties of concrete.

Bloem (1968) conducted research measuring the compressive strength of concrete cylinders and cores. The cores were taken from Slab Specimens that were "well" cured and "poorly" cured. The "well" cured Slab Specimens were sprayed with curing compound and covered with wet burlap and plastic for 14 days. The forms were removed at 28 days and the slab was raised 6 in. from the floor to permit drying from all surfaces. The "poorly" cured Slab Specimens were left uncovered after placement and the forms were stripped 3 days after placement. These specimens were also raised 6 in. from the floor to allow drying from all surfaces. Each Slab Specimen was cast with push-out cylinders using special plastic inserts for cast-in-place cylinders. Drilled cores were also obtained from the slabs. Molded cylinders were cast for each slab; some were moist cured and some were field cured. The major findings of the study were that the strength of drilled cores were less than that of moist-cured cylinders tested at the same age; this deficiency was more pronounced for the "poorly" cured concrete; field-cured cylinders did not give a good representation of the concrete as measured by cores and were less adversely affected by improper curing than were the cores from the slab; and the push-out cylinders cast in the Slab Specimens provided the most reliable measure of core strength.

Thomas et al. (1989) examined the effect of curing on the strength, oxygen permeability, and water permeability of portland cement concrete and portland cement/fly ash concrete. The specimens were moist-cured with burlap for 1, 2, 3, or 7 days, while the control specimens were wet-cured in a water tank until testing. Not surprisingly, Thomas et al. found that compressive strength increased as the duration of the curing increased. The increase in strength was more noticeable in the concretes containing fly ash than in the portland cement concrete. They found that the concrete containing fly ash was less permeable to oxygen than similarly cured OPC portland cement concrete, and that both concrete types had similar water permeability. Thomas et al. stated that initial curing is vital to ensure adequate durability of the concrete.

Nassif and Suksawang (2002) examined the effect of curing procedure on concrete properties, such as strength, shrinkage, chloride permeability, and freeze-thaw performance. Test specimens were subjected to six different curing regimes – moist curing at a relative humidity of 95%, air-curing, application of a commercially available curing compound, and wet burlap for 3, 7, or 14 days. The concrete that was moist-cured had the highest strength at 28 days while the specimens that were cured in air, with curing compound, or with burlap had about 12% lower strength. They also found that moist curing and curing with burlap for 14 days is essential to achieve a specified charge passed of < 1,000 coulombs at 56 days using the Rapid Chloride Permeability test, a qualitative measure of the permeability of a concrete mixture. They concluded that the use of a curing compound is not as effective as the other curing methods and that any of the four methods evaluated should be continued for a minimum of 14 days to ensure adequate strength and durability.

1.4 Project Objectives and Scope

The goal of this project is to provide a better understanding of changes in strength, permeability, and porosity of concrete over time with and without supplementary cementitious materials by evaluating the effects of specimen type and curing conditions. Three mixtures were evaluated by the University of Kansas (KU): a control mixture with 100% portland cement (PC), a mixture with 35% replacement (by weight) with slag cement, and a mixture with 15% replacement with fly ash and 25% replacement with slag cement. One slab made with each mixture was cast in the summer, fall, and spring to evaluate the performance of the mixtures under varying environmental conditions. Companion research performed by Kansas State University evaluated mixtures with Class C and Class F fly ash.

Compressive strength (ASTM C39), rapid chloride permeability (RCP) (ASTM C1202), and boil (KT-73) tests were performed on lab-cured cylinders, field-cured cylinders, and cores from each slab. Results from these tests were used to determine how the strength, permeability, and porosity of the concrete changed over time, how the environmental conditions at early ages affected these properties, and how specimen type (lab-cured cylinders, field-cured cylinders, and cores) affected the results. Furthermore, results from the boil test and RCP test were compared to determine if any correlation between the two methods exists. This report details the results and conclusions derived from the research at KU.

CHAPTER 2: EXPERIMENTAL WORK

2.1 Introduction and Test Program

This chapter describes the site preparation, casting procedure, and tests performed on the slabs and cylinders cast for this project. The University of Kansas (KU) test program included three concrete mixtures with cementitious material contents of (1) 100% portland cement (PC), (2) 35% slag and 65% portland cement, and (3) 15% class C fly ash, 25% slag, and 60% portland cement. The aggregate gradations in the KU mixtures were optimized using the KU Mix design program: (https://iri.drupal.ku.edu/node/43).

Concrete slabs, 8-ft square and 10 in. thick, were cast in the field under three different seasonal conditions during summer 2011, fall 2011, and spring 2012. Three sets of specimens (lab-cured cylinders, field-cured cylinders, and cores from the 10-in. concrete slabs) were tested at 28, 56, 90, 180, 360, and 720 days for strength and permeability properties. Strength (ASTM C39) and boil (KT-73) tests were conducted at KU. Rapid chloride permeability tests (RCPT, ASTM C1202) were conducted at the Kansas Department of Transportation (KDOT) Research Laboratory. Temperature sensors were embedded in each slab and in two field-cured cylinders for each slab.

An additional series of permeability tests was performed to compare the results obtained from the boil test and RCPT with those obtained in the AASHTO T 259 ponding test. In that series, three specimens for each mixture were cast in the laboratory with air contents of 5 to 6%, 7 to 8%, and 9 to 10%. Specimens were cured in lime-saturated water for 28, 56, or 90 days prior to testing. The RCPT specimens were evaluated by the KDOT Research Laboratory; boil test specimens and AASHTO T 259 specimens were evaluated at KU.

2.2 Slab and Cylinder Casting Procedure

The procedure for casting the slabs followed the guidelines outlined in Section 501, Portland Cement Concrete Pavement (QC/QA), of the "Standard Specifications for State Road & Bridge Construction" (KDOT 2007). In preparation for concrete placement, the formwork for each slab was placed and the subgrade leveled. Formwork consisted of four 1.5 in. × 10 in. × 8 ft lengths of lumber. The formwork was held square with two L-brackets at each corner and held in place with wooden stakes driven into the ground and attached to the forms. The formwork was checked with a bubble level and adjusted as needed. The subgrade consisted of a 4-in. thick layer of AB-3 aggregate.

Upon arrival of the concrete truck, initial slump and air (pressure method) tests were performed to determine if the concrete met KDOT specifications (air between 4 and 10%, slump ≤ 4 in.) (KDOT 2007). If the slump or air content were too high, the concrete was held and mixed on site until the slump and air content decreased to acceptable levels. Once the concrete met KDOT specifications, the slab was placed. After the first third of the slab was placed, the concrete stream was fully diverted into a wheelbarrow and approximately 5 ft^3 of concrete collected for testing. An additional 5 ft^3 of concrete was collected after two-thirds of the slab was placed. These two samples were combined and used to measure slump, temperature, and air content, and prepare the lab and field-cured cylinders. The slab was consolidated using a handheld vibrator and finished with a vibrating screed and bullfloat. A curing compound (Sealtight 1610) was applied using a pump sprayer immediately after bullfloating.

Test cylinders were 4 in. by 8 in. and were made in accordance with the procedures outlined in ASTM C31. The cylinders were numbered 1-120 and were filled by two teams, with Team 1 filling cylinders 1 through 60 and Team 2 filling cylinders 61 through 120. Odd-numbered cylinders were used as lab-cured cylinders, and even-numbered cylinders were used as field-cured cylinders. As will be explained in Section 2.4.1, test cylinders were selected from the beginning, middle, and end of the cylinder-making process for both teams to minimize differences due to variations in the concrete. The lab-cured cylinders were stored in a shed for the first 24 hours, with ice, if needed, to control the air temperature adjacent to the cylinders. The field-cured cylinders were stored outdoors in a wire cage to protect them from being disturbed. The cage was located close to the slabs to ensure that the field-cured cylinders and slab experienced the same environmental conditions. Due to the nature of the storage containers for the field-cured cylinders, some cylinders were exposed to direct sunlight while others were partially shielded from the sun. The slab and all cylinders were demolded after 24 hours. The lab-cured cylinders were moved to KU 24 hours after casting and stored in lime-saturated water until testing; the field-cured cylinders remained at the field site until about one week prior to testing.

To monitor the temperature of the concrete during setting and curing, temperature probes were cast in the concrete for each slab. A total of four probes were used for each mixture; two probes were cast in the slab, and one probe was placed in each of two specially-marked cylinders. These cylinders were not used in the strength and permeability tests. The probes consisted of a Thermochron DS1921G iButton with test leads attached to allow the sensor to be read while buried in concrete. The probes were covered with a thick layer of SewerGuard HBS 100 Epoxy Liner to protect them from the concrete environment. Just prior to casting, a U-shaped reinforcing bar was driven into the ground two feet from the south and west edges of the slab and adjusted so that the top of the U would be 5 in. below the finished surface of the slab. Two temperature probes were attached to this reinforcing bar to monitor the slab temperature. The test leads were guided out the side of the slab through a notch cut in the formwork. The cylinder probes were placed in the center of the marked cylinders after the cylinders were half filled. The test leads were guided out the top of the cylinder and were held as the cylinder was filled and finished. The probes provided temperature readings every 10 minutes for the first week and hourly thereafter.

2.3 Mixture Proportions, Material Properties, and Slab Placement

2.3.1 100% Portland Cement (PC) Mixture

2.3.1.1 Mixture Proportions

The 100% portland cement (PC) mixture was designed to have a cement content of 520 lb/yd^3 and a water-cement (*w/c*) ratio of 0.42. Three aggregates–limestone coarse aggregate, pea gravel, and sand–were used and proportioned using the KU Mix design program to optimize the aggregate gradations. Admixtures included W. R. Grace Adva 140 (ASTM C494, Type A and F) water reducer, Daravair 1400 air entraining agent, and in one slab, Daratard 17 (ASTM C494, Type B and D) set retarder. The proportions and combined gradation are shown in Table 2.1 and Figure 2.1, respectively.

Table 2.1: Proportions for the 100% Portland Cement (PC) Mixture

Material / Source or Designation / Blend	Quantity (SSD)	S.G.	Yield, ft^3
Type I/II Cement / Lafarge / 100%	520 lb	3.15	2.65
Water	213 lb	1.00	3.41
Limestone / C-33 / 46.51%	1432 lb	2.54	9.03
Sand / VPSAND / 32.28%	994 lb	2.62	6.08
Pea Gravel / KPSA1 / 21.21%	653 lb	2.63	3.98
Total Air, percent	6.5%		1.76
Daravair 1400	7 fl oz (US)	1.01	0.00
Adva 140	68 fl oz (US)	1.20	0.09
Daratard 17*	16 fl oz (US)	1.17	0.00

*Used only in summer slab with 100% portland cement mixture.

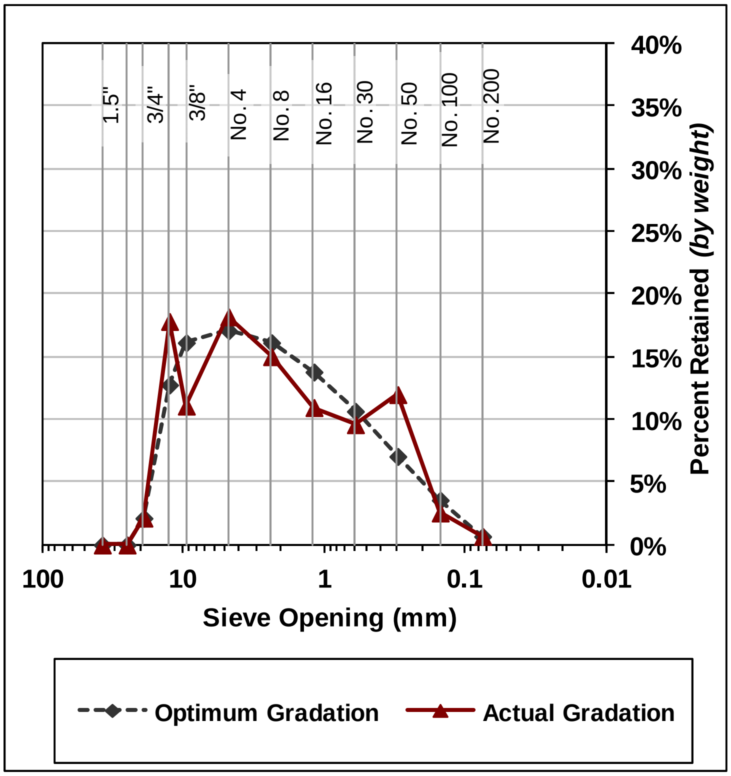

Figure 2.1: Combined aggregate gradation (optimized) for the 100% portland cement (PC) mixture

2.3.1.2 Concrete Testing and Placement

Summer: A trial slab was placed on July 25, 2011. To minimize the time of delivery, the concrete was not tested at the ready-mix plant, where it was visually estimated to have a 3-in. slump. When the concrete truck arrived at the job site, about 50 minutes after batching, the slump was only 0.25 in. and the concrete temperature was 90 °F. Extra water reducer was added several times at the job site over the following 30 minutes. The slump was brought back to 1.5 in., the air content was 5.4%, and the concrete temperature was 91 °F. The slab was cast but the concrete was very difficult to consolidate and finish. Only half the required number of cylinders could be fabricated, and the slab could not be fully consolidated. This slab was not used for testing.

After discussions with KDOT and the material supplier, it was decided to use chilled water and ice to reduce the concrete temperature. The ice was added at the central mixer to ensure proper mixing of the concrete. One day before the slab was placed, two 1-yd^3 trial batches were made at the ready-mix plant using chilled water and ice to control the concrete temperature to demonstrate that in-specification concrete could be made.

The summer slab with the 100% portland cement mixture was cast on July 28, 2011. The concrete had a slump of 7 in., an air content of 13.4%, and a temperature of 89 °F when it arrived at the job site (40 minutes after batching). The concrete was mixed for about 35 minutes to let the slump and air content decrease. The slump was 4 in. and the air content was 9.4% when the slab was placed. When the composite sample of concrete was tested in the middle of Slab Placement, it had a slump of 3¾ in., an air content of 7.9%, a temperature of 90 °F, and a unit weight of 140.3 lb/ft^3. The *w/c* ratio based on the trip ticket was 0.43.

Fall: The fall slab with the 100% portland cement mixture was cast on October 19, 2011. No ice or chilled water was used. The concrete had a slump of 2 in., an air content of 8.4%, and a temperature of 68 °F when it arrived at the job site (50 minutes after batching). The slab and cylinders were then cast. When the composite sample of concrete was tested, it had a slump of 1¼ in., an air content of 7.4%, a temperature of 66 °F, and a unit weight of 141.0 lb/ft^3. The *w/c* ratio for Slab U1 based on the trip ticket was 0.42.

Spring: The spring slab with the 100% portland cement mixture was cast on April 5, 2012. The concrete had a slump of 0.25 in., an air content of 6.0%, and a temperature of 69 °F when it arrived at the job site (50 minutes after batching). Due to the low slump, Adva 140 was added on site. This increased the slump to 1.75 in. and the air content to 6.4%. The slab and cylinders were then cast. When the composite sample of concrete was tested, it had a slump of 0.75 in., an air content of 6.0%, and a temperature of 72 °F. The unit weight was 147.9 lb/ft^3, a value that is clearly too high for the measured air content and materials used, and in all likelihood the result of an error in measurement. The *w/c* ratio for Slab P1 based on the trip ticket was 0.40.

2.3.2 65% Portland Cement/35% Slag (PC/S)

2.3.2.1 Mixture Proportions

The second mixture was designed to have a 35% replacement, by weight, of cement with slag cement, a total cementitious material content of 520 lb/yd^3, and a *w/cm* ratio of 0.42. The three aggregates used for the 100% portland cement (PC) mixture were used to provide the optimized aggregate gradation, along with the same admixtures. The mixture proportions and combined gradation are shown in Table 2.2 and Figure 2.2, respectively. The principal difference in gradation from the 100% portland cement mixture was a small reduction in sand because of the higher volume of cementitious material due to the lower specific gravity of slag cement compared to portland cement.

Table 2.2: Proportions for the 65% Portland Cement/35% Slag (PC/S) Mixture

Material / Source or Designation / Blend	Quantity (SSD)	S.G.	Yield, ft^3
Type I/II Cement / Lafarge / 65%	338 lb	3.15	1.72
Slag / Lafarge / 35%	182 lb	2.89	1.01
Water	214 lb	1.00	3.43
Limestone / C-33 / 46.69%	1432 lb	2.54	9.03
Sand / VPSAND / 31.89%	978 lb	2.62	5.98
Pea Gravel / KPSA1 / 21.42%	657 lb	2.63	4.00
Total Air, percent	6.5%		1.76
Daravair 1400	6.5 fl oz (US)	1.01	0.00
Adva 140	70 fl oz (US)	1.20	0.05

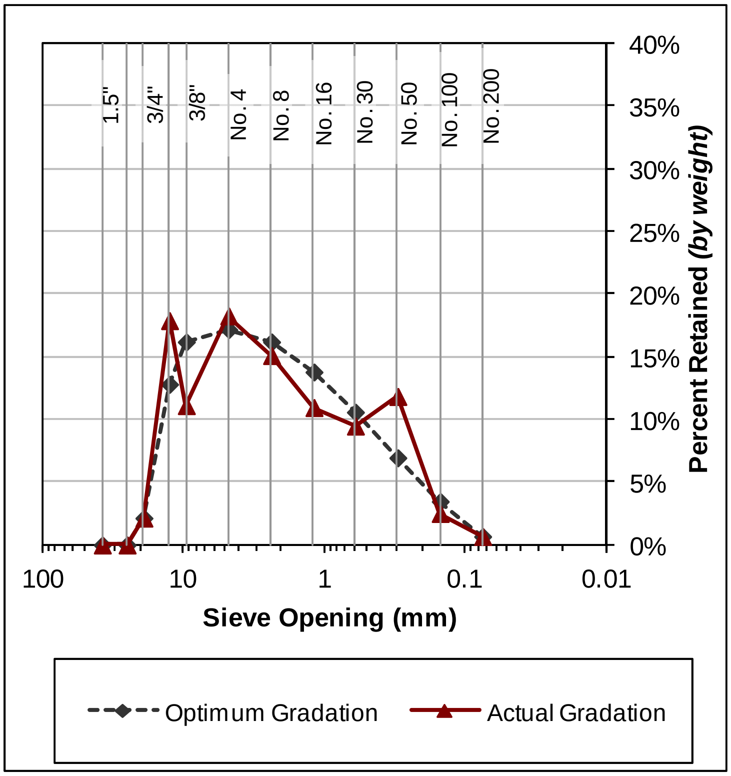

Figure 2.2: Combined aggregate gradation (optimized) for the 65% portland cement/35% slag (PC/S) mixture

2.3.2.2 Concrete Testing and Placement

Summer: The summer slab with the 65% portland cement/35% slag mixture was cast on August 16, 2011. The air temperature was 79 °F. No set retarder was used. Chilled water was used to control the concrete temperature. The concrete had a slump of 5.5 in., an air content of 10.4%, and a temperature of 81 °F when it arrived at the job site (40 minutes after batching). The concrete was mixed for another 20 minutes to let the slump and air content decrease. The slump was 4 in. and the air content was 9.4% when the slab was cast. When the composite sample of concrete was tested, about 80 minutes after batching, it had a slump of 3 in., an air content of 5.8%, a temperature of 81 °F, and a unit weight of 143.0 lb/ft^3. The *w/cm* ratio based on the trip ticket was 0.41.

Fall: The fall slab with the 65% portland cement/35% slag mixture was cast on November 3, 2011. Because the air temperature was low, cement hydration was slow and casting speed was not as critical as for the summer concrete placements. The concrete was tested in the plant before it was sent to the field. The concrete had a slump of 1.25 in. and an air content of 7% at the plant. Extra water reducer was added and the concrete was delivered. The concrete had a slump of 1.5 in., an air content of 6.4%, and a temperature of 64 °F when it arrived at the job site. The slab and cylinders were cast. When the composite sample of concrete was tested, the slump was 1.25 in., the air content was 5%, the temperature was 64 °F, and the unit weight was 144.0 lb/ft^3. Because freezing conditions were predicted following placement, an insulated blanket was placed over the slab and cylinders. The blanket was left over the concrete and the field cured cylinders for the first seven days of curing. The *w/cm* ratio based on the trip ticket was 0.42.

Spring: The spring slab with the 65% portland cement/35% slag mixture was cast on April 19, 2012. The concrete had a slump of 2 in., an air content of 9.0%, and a temperature of 75 °F when it arrived at the job site. The slab and cylinders were cast without problems. When the composite sample of concrete was tested, the slump was 1.5 in., the air content was 7.4%, the temperature was 78 °F, and the unit weight was 143.3 lb/ft^3. The *w/cm* ratio based on the trip ticket was 0.40.

2.3.3 60% Portland Cement/25% Slag/15% Class C Fly Ash (PC/S/FA)

2.3.3.1 Mixture Proportions

The third mixture had a 15% weight replacement of portland cement by Class C fly ash and a 25% weight replacement of portland cement by slag cement, a total cementitious material content of 520 lb/yd^3, and a *w/cm* ratio of 0.42. Three aggregates were again used to provide the optimized aggregate gradation, along with the same admixtures as used for the 100% portland cement mixture. The mixture proportions and combined gradation are shown in Table 2.3 and Figure 2.3, respectively.

Table 2.3: Proportions for the 60% Portland Cement/25% Slag/15% Class C Fly Ash (PC/S/FA) Mixture

Material / Source or Designation / Blend	Quantity (SSD)	S.G.	Yield, ft³
Type I/II Cement / Lafarge / 60%	312 lb	3.15	1.59
Slag / Lafarge / 25%	130 lb	2.89	0.72
Class C fly ash / Lafarge / 15%	78 lb	2.75	0.45
Water	216 lb	1.00	3.46
Limestone / C-33 / 46.76%	1431 lb	2.54	9.03
Sand / VPSAND / 31.73%	971 lb	2.62	5.94
Pea Gravel / KPSA1 / 21.5%	658 lb	2.63	4.01
Total Air, percent	6.5%		1.76
A/E Daravair 1400	3.7 fl oz (US)	1.01	0.00
Adva 140	44.2 fl oz (US)	1.20	0.04

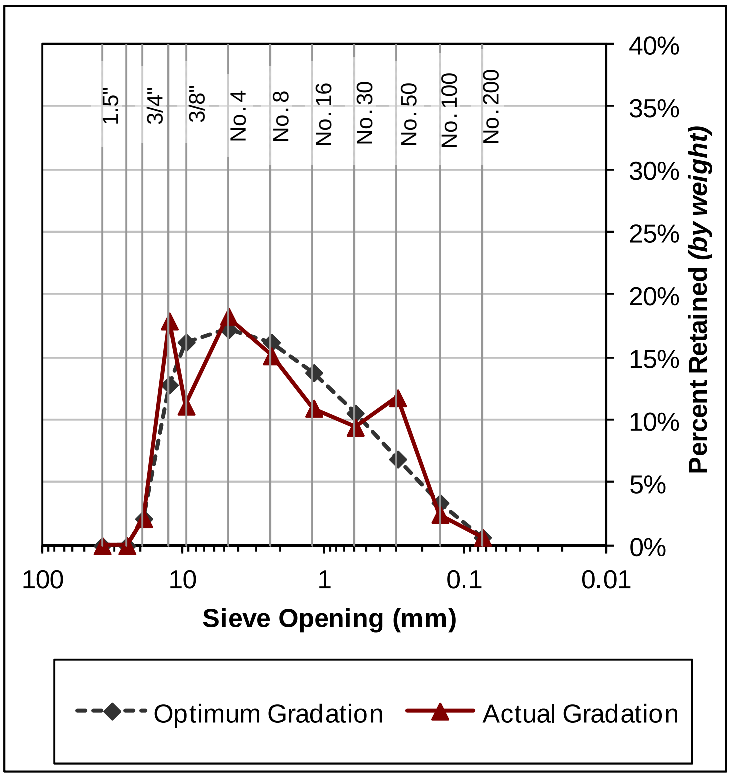

Figure 2.3: Combined aggregate gradation (optimized) for the 60% portland cement/25% slag/15% class c fly ash (PC/S/FA) mixture

2.3.3.2 Concrete Testing and Placement

Summer: The summer slab with the 60% portland cement/25% slag/15% Class C fly ash mixture was cast on August 24, 2011. Because the air temperature was high (around 90 °F), ice was used to partially replace the mix water. The concrete had a slump of 7 in. and a temperature of 80 °F when it arrived at the job site (45 minutes after batching). The concrete was mixed for another 20 minutes, after which the slump was 6 in. and the air content was 10.4%. It took another 70 minutes before the slump decreased to 4 in. When the composite sample of concrete was tested, it had a slump of 2.5 in., an air content of 5.4%, and a temperature of 86 °F. Due to problems with the scale, the unit weight was not taken. The *w/cm* ratio based on the trip ticket was 0.42.

Fall: The fall slab with the 60% portland cement/25% slag/15% Class C fly ash mixture was cast on November 9, 2011. The concrete was dry batched due to problems with the central mixer at the ready-mix plant. The concrete had an initial slump of 7 in., an air content of 17%, and a temperature of 54 °F at the plant. To correct for the high air content, another cubic yard of concrete was added to the concrete truck without any admixtures. The concrete had a slump of 4.5 in., an air content of 9%, and a temperature of 52 °F when it arrived at the job site (100 minutes after batching). The concrete was mixed for approximately another 30 minutes to let the slump decrease to 4 in. When the composite sample of concrete was tested, the slump was 4 in., the air content was 7.4%, the temperature was 54 °F, and the unit weight was 139.0 lb/ft^3. To protect the slab from freezing, an insulated blanket was placed over the slab and cylinders for the first seven days of curing, similar to the fall slab with the 65% portland cement/35% slag (PC/S) mixture. The *w/cm* ratio based on the trip tickets was 0.39.

Spring: The spring slab with the 60% portland cement/25% slag/15% Class C fly ash was cast on April 26, 2012. The concrete had a slump of 1 in., an air content of 10%, and a temperature of 83 °F when it arrived at the job site. Due to the low slump, Adva 140 was added, after which the slab and cylinders were cast. When the composite sample of concrete was tested, the slump was 2.25 in., the air content was 9.0%, the temperature was 83 °F, and the unit weight was 144.2 lb/ft^3. The *w/cm* ratio based on the trip tickets was 0.42.

2.2.4 Summary

The concrete properties and air temperature for the nine slabs are summarized in Table 2.4.

Table 2.4: Plastic Concrete Properties

Season	Concrete	Casting Date	Slump (in.)	Air Temp (°F)	Concrete Temp (°F)	Unit Wt. (lb/ft^3)	Air (%)	*w/cm* ratio$^+$
Summer	100% Portland Cement (PC)	7/28/2011	3¾	92	90	140.3	7.9	0.43
	65% PC, 35% Slag (PC/S)	8/16/2011	3	79	81	143.0	5.8	0.41
	60% PC, 25% Slag, 15% Fly Ash (PC/S/FA)	8/24/2011	2½	90	86	*	5.4	0.42
Fall	100% Portland Cement (PC)	10/19/2011	1¼	43	66	141.0	7.4	0.42
	65% PC, 35% Slag (PC/S)	11/3/2011	1¼	40	64	144.0	5.0	0.42
	60% PC, 25% Slag, 15% Fly Ash (PC/S/FA)	11/9/2011	4	44	54	139.0	7.4	0.39
Spring	100% Portland Cement (PC)	4/5/2012	¾	55	72	147.9**	6.0	0.40
	65% PC, 35% Slag (PC/S)	4/19/2012	1½	78	78	143.3	7.4	0.40
	60% PC, 25% Slag, 15% Fly Ash (PC/S/FA)	4/26/2012	2¼	89	83	144.2	9.0	0.42

$^+$Based on trip ticket
* Measurement not obtained
** High value – likely in error

2.4 Sample Collection and Test Procedures

2.4.1 Selecting Test Specimens for Testing

The cylinders were tested following the plan outlined in Table 2.5. The test plan was designed to ensure each test involved cylinders filled at the beginning, middle, and end of the cylinder-making process. In the event that a cylinder was damaged or otherwise unsuitable for testing, one of the extra cylinders was chosen to replace it. Field-cured cylinders remained in the field until approximately one week prior to testing, at which time they were brought to the KU Concrete Laboratory and maintained at 70 to 74 °F until the time of test. Lab-cured cylinders were brought to the KU Concrete Laboratory approximately 24 hours after casting and were cured in lime-saturated water in accordance with ASTM C31 until they were prepared for testing.

Table 2.5: Lab and Field Cured Cylinder Test Schedule*

Cylinders	Test Age, days	Strength	Boil	RCPT	Strength	Boil	RCPT	Strength	Boil	RCPT	Extras
Field	28	2	16	30	44	56	70	84	98	110	14
	56	4	18	32	46	58	72	86	100	112	28
	90	6	20	34	48	60	74	88	102	114	42
	180	8	22	36	50	62	76	90	104	116	68
	360	10	24	38	52	64	78	92	106	118	82
	720	12	26	40	54	66	80	94	108	120	96
Lab	28	1	15	29	43	55	69	83	97	109	13
	56	3	17	31	45	57	71	85	99	111	27
	90	5	19	33	47	59	73	87	101	113	41
	180	7	21	35	49	61	75	89	103	115	67
	360	9	23	37	51	63	77	91	105	117	81
	720	11	25	39	53	65	79	93	107	119	95

*Numbers refer to the order in which cylinders were made on casting day

The slabs were cored approximately one week prior to the testing date using a 4.25-in. diameter core bit, following the procedures outlined in KT-49. This bit produced a core with a nominal diameter of 4 in. Cores were taken perpendicular to the Slab Surface. After coring, the

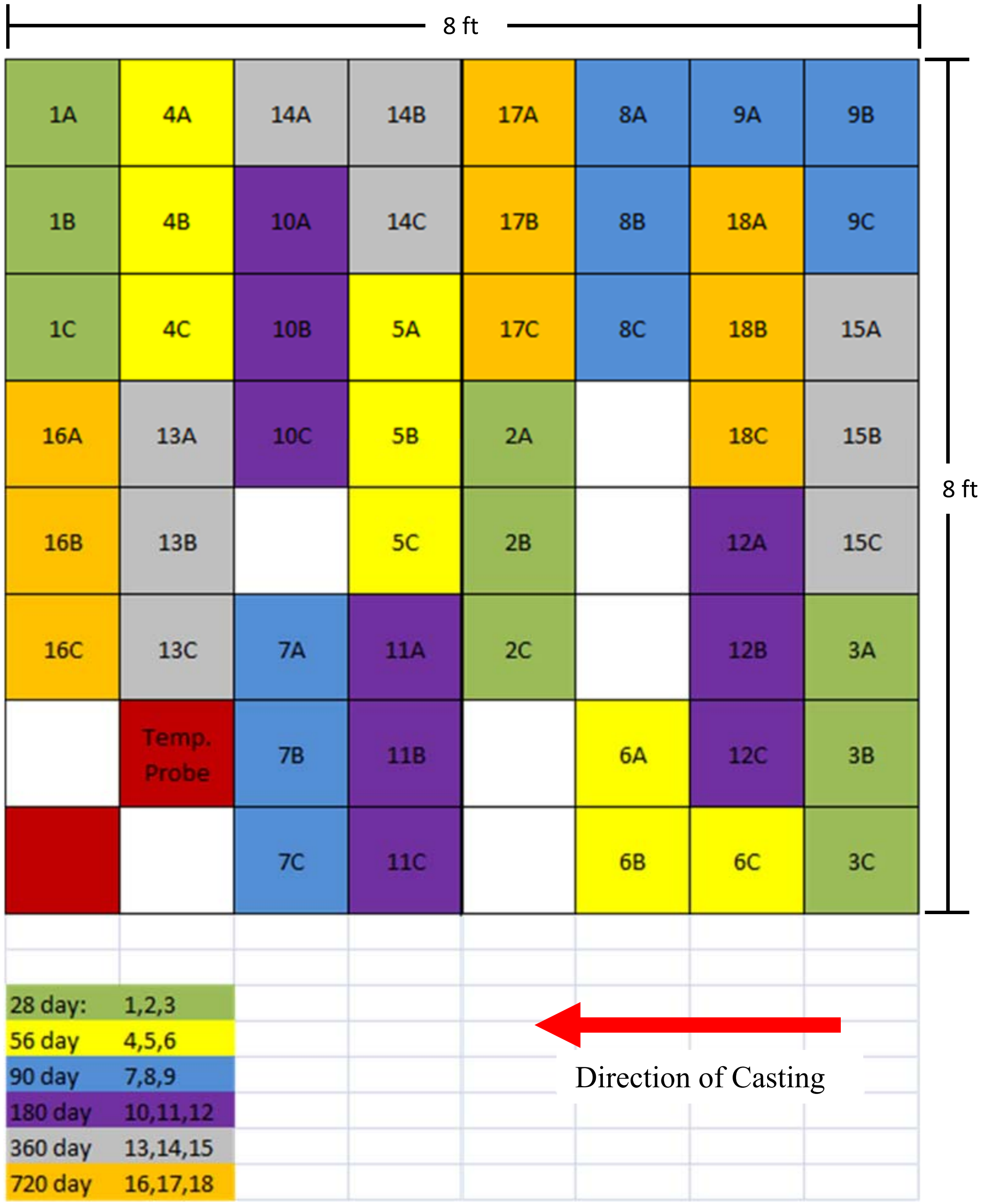

Figure 2.4: Slab coring map.

water from drilling was wiped off and the surface allowed to dry. The cores were labeled with slab and location information and placed in sealed plastic bags to limit additional moisture loss. The cores were returned to KU and stored in the lab at 70 to 74 °F until testing. For each test date, three cores were taken from each of three locations on the slab, for a total of nine cores per test date. A map of core locations is shown in Figure 2.4. The coring locations were chosen so that, for each test, concrete from the beginning, middle, and end of the placement was sampled. Each test (strength, boil, and permeability) used one core from each location; strength testing was performed on A cores, boil testing on B cores, and RCP testing on C cores (see Figure 2.4).

On the day of strength testing, the unfinished end of the core was cut level with a masonry saw, and the core length both before and after cutting recorded. The cores and cylinders were then capped using sulfur capping compound at least two hours prior to testing.

2.4.2 Test Procedures

2.4.2.1 Compressive Strength Test

The specimens were tested in accordance with ASTM C39. Three lab-cured cylinders, three field-cured cylinders, and three cores were tested on each test date. Prior to testing the cores, the bottom ends were cut level using a masonry saw, but otherwise the full length was retained to provide as representative a sample as possible for evaluation of the concrete through the depth of the slab. Because the cores were longer than 8 in., it was necessary to adjust the strength of the cores to correct for the fact that the length-to-diameter ratio was not equal to 2. The final compressive strength was adjusted using the following equations (KDOT 2007):

For ${}^{L}/_{D} < 2$;

$$\sigma = \sigma_u \left[\frac{100}{95 + 0.2\left(\frac{D}{L}\right) + 19.5\left(\frac{D}{L}\right)^2} \right]$$

For ${}^{L}/_{D} > 2$;

$$\sigma = \sigma_u \left[\frac{100}{110 - 5\left(\frac{L}{D}\right)} \right]$$

where:

D = core diameter, in.
L = core length, in.
σ_u = uncorrected compressive strength, psi.
σ = corrected compressive strength, psi
Strengths reported for cores are corrected compressive strengths.

2.4.2.2 Boil Test

The boil test was performed in accordance with KDOT Test Method KT-73. Three lab-cured cylinders, three field-cured cylinders, and three cores were tested at each test date. A description of the procedure follows:

1) The finished top portion of the cylinder or core is cut off with a masonry saw and discarded. The cut is made such that the discarded section is no more than 0.375-in. thick.
2) A 2-in. thick disk is taken from the top of the cylinder or core below the cut-off end and used as the sample for the boil test. The initial mass of each sample is taken and recorded.
3) Samples are oven-dried to a constant mass at a temperature of 212 to 230 °F. Every 24 hours, samples are removed from the oven, allowed to cool, and weighed. A constant mass is considered to have been reached when the masses at two consecutive weighings varies by less than 0.5%. This mass is recorded as Mass ‘A’.
4) The specimens are submerged in water at approximately 70 °F until a constant mass is obtained. Every 24 hours, samples are removed from the water, towel dried to remove surface moisture, and weighed. Again, a constant mass is considered to have been reached when the masses at two consecutive weighings varies by less than 0.5%. This mass is recorded as Mass ‘B’.
5) Specimens are submerged in boiling water for 5 hours and kept a minimum of 0.25 in. from the bottom of the container using a wire mesh false bottom in the boiling container. After boiling, specimens are cooled by natural loss of heat for not less than 14 hours to a final temperature of 68 to 77 °F.
6) Samples are suspended by a wire and weighed to determine the apparent mass in water. This mass is recorded as Mass ‘D’.

7) Specimens are removed from the water, towel dried to remove surface moisture, and weighed. This mass is recorded as Mass 'C'.

Calculations are as follows:

Absorption after immersion, %:

$$\frac{B-A}{A}\times 100$$

Absorption after immersion and boiling, %:

$$\frac{C-A}{A}\times 100$$

Bulk density, dry:

$$\frac{A}{C-D}\times \rho$$

Bulk density after immersion:

$$\frac{B}{C-D}\times \rho$$

Bulk density after immersion and boiling:

$$\frac{C}{C-D}\times \rho$$

Apparent density:

$$\frac{A}{A-D}\times \rho$$

Volume of permeable pore space (voids), %:

$$\frac{C-A}{C-D}\times 100$$

where:

A = mass of oven dried sample in air,
B = mass of surface-dry sample in air after immersion
C = mass of surface-dry sample in air after immersion and boiling
D = apparent mass of sample in water after immersion and boiling
ρ = density of water

2.4.2.3 RCP Test

The Rapid Chloride Permeability test (RCP test) was performed at the KDOT Materials and Research Center in accordance with ASTM C1202. The RCP test measures the current passed through a 2-in. thick sample of concrete taken from a cylinder or core. One side of the test specimen is exposed to a sodium chloride solution while the other side is exposed to a sodium hydroxide solution. A greater charge passing through the specimen suggests a greater ionic permeability (ASTM C1202). Three lab-cured cylinders, three field-cured cylinders, and three cores were tested at each test date.

2.5 AASHTO T 259 Ponding Specimens

In addition to the slab specimens cast in the field, laboratory ponding specimens were cast to compare the results obtained with the boil test and RCP test with those obtained in the AASHTO T 259 ponding test. The 100% portland cement (PC) mixture, with a cement content of 520 lb/yd^3 and a water-cement (*w/c*) ratio of 0.42, was used for this portion of the study. The materials and mixture proportions used in the field slabs were used for the ponding specimens, except the dosage of chemical admixtures was adjusted to obtain the desired air content. The plastic concrete properties of the three laboratory series are summarized in Table 2.6.

Table 2.6: Plastic Concrete Properties for Ponding Specimens

Concrete	Casting Date	Air (%)	Slump (in.)	Concrete Temp (ºF)
100% Portland Cement (PC)	9/27/2011	9.15	2¾	72
100% Portland Cement (PC)	10/4/2011	7.65	2½	73
100% Portland Cement (PC)	10/13/2011	5.90	1½	70

2.5.1 Specimen Design and Preparation

AASHTO T 259 ponding specimens are 12 × 12 × 3 in., with a ¾-in. dam cast integrally with the specimen. The specimens are cast upside down in two layers. After each layer of concrete is filled, the specimens are vibrated for a minimum of 30 seconds and maximum of 60 seconds on a vibration table with an amplitude of 0.006 in. and a frequency of 60 Hz. Excess concrete is then removed using a 4 × 1 in. wooden screed. Specimens are demolded after 24 hours and placed in tanks with saturated limewater for the duration of the curing period. Specimens are cured for 28, 56, or 90 days and then allowed to dry for 28 days prior to testing.

2.5.2 Test Procedure

After curing and drying, the specimens are tested as follows:

1) Specimens are ponded with a 3% NaCl solution for 90 days. Specimens are kept covered with plastic sheeting to minimize evaporation.

2) After 90 days of ponding, the solution is removed and three cores are taken from each specimen in accordance with KDOT Test Method KT-49.

3) Each core is sampled for chlorides using the following procedure:

   i. The core is secured right-side up in a milling machine fitted with a diamond core grinding bit.

   ii. The top 0.04 in. of concrete is removed from the core using the milling machine and the powder discarded.

   iii. The core is milled from 0.04 to 0.10 in. in depth. This powder is collected and used for chloride analysis.

   iv. Additional chloride samples are taken at depths of 0.2 to 0.3 in., 0.4 to 0.5 in., 0.6 to 0.8 in., and 0.8 to 1.0 in.

   v. The water-soluble chloride content of each sample is determined in accordance with AASHTO T 260-97, "Standard Method of Test for Sampling and Testing for Chloride Ion in Concrete and Concrete Raw Materials."

   vi. The chloride content at various depths of each core is used to find the effective diffusion coefficient D_{eff} and surface chloride content using Fick's Second Law:

$$\frac{\partial C}{\partial t} = D_{eff} \frac{\partial^2 C}{\partial x^2}$$

Assuming a constant chloride content at the surface C_o and a chloride content of 0 at an infinite depth, the solution to Fick's Second Law becomes:

$$C(x,t) = C_o\left[1 - erf\left(\frac{x}{\sqrt{4D_{eff}t}}\right)\right]$$

where:

$C(x,t)$ = chloride content at depth x and time t
C_o = surface chloride concentration
erf = error function
x = depth at which a chloride sample was obtained
D_{eff} = effective diffusion coefficient
t = time of chloride exposure at time of sampling

The values for D_{eff} and C_o are chosen to minimize the deviation between the solution to Fick's Second Law and the chloride concentrations obtained in part 3v. of the test procedure using the least squares method.

In addition to the permeability test, strength, boil, and RCP tests are performed on 4 × 8 in. cylinders cast at the same time as the permeability specimens. These tests are performed as described in Section 2.4. Three specimens of each type were prepared and tested in this portion of the study.

CHAPTER 3: RESULTS AND ANALYSIS

This chapter describes the results of temperature monitoring, compressive strength, RCP, and boil tests performed on each of the nine slabs and corresponding cylinders cast in this project. The results from the AASHTO T259 permeability specimens are also presented. An analysis of the results follows each section.

3.1 Temperature Monitoring Results

Each slab had two temperature probes cast internally; two additional probes were placed in concrete cylinders. In general, all slabs exhibited similar behavior with regards to temperature. The temperature profile for the summer slab with 100% PC is shown in Figures 3.1a and 3.1b; the 100% PC mixtures cast in the fall and spring exhibited similar behavior and are presented in Appendix A. Slabs exhibited a high peak internal temperature from curing in the first 24 hours, cooling to ambient temperature within 2-3 days. Cylinders exhibited a lower peak temperature in the first 24 hours than slabs; cylinders exhibited greater variations in internal temperature than slabs after 24 hours, as their lower thermal mass left them more susceptible to variations in ambient conditions.

The temperature profile for the summer slab with 65% PC/35% S is shown in Figures 3.2a and 3.2b; the mixtures with SCM's cast in the fall and spring exhibited comparable behavior and are presented in Appendix A. Slabs containing SCM's exhibited a lower peak temperature during curing than slabs containing 100% PC; however, the slab temperature remained elevated for 2-3 days before decreasing to ambient temperatures, as opposed to 1 day for 100% PC mixtures. As was observed in the 100% PC specimens, cylinders generally exhibited a lower peak curing temperature and greater variation with ambient temperature than slabs.

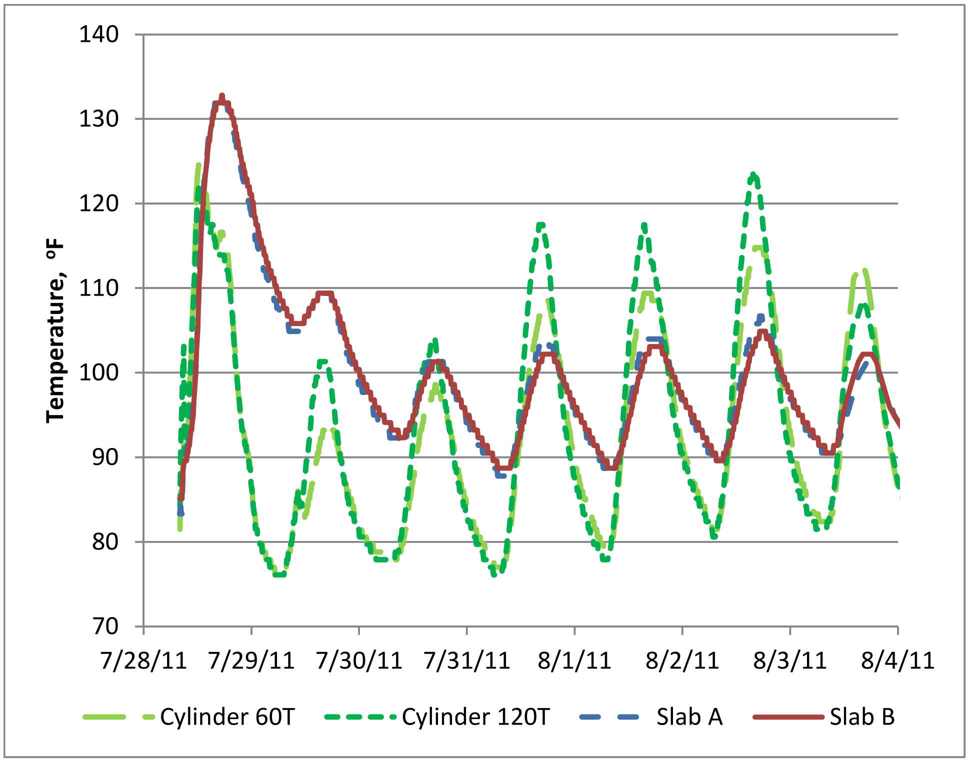

Figure 3.1a: Temperature vs. time for summer slab with 100% portland cement (PC) mixture.

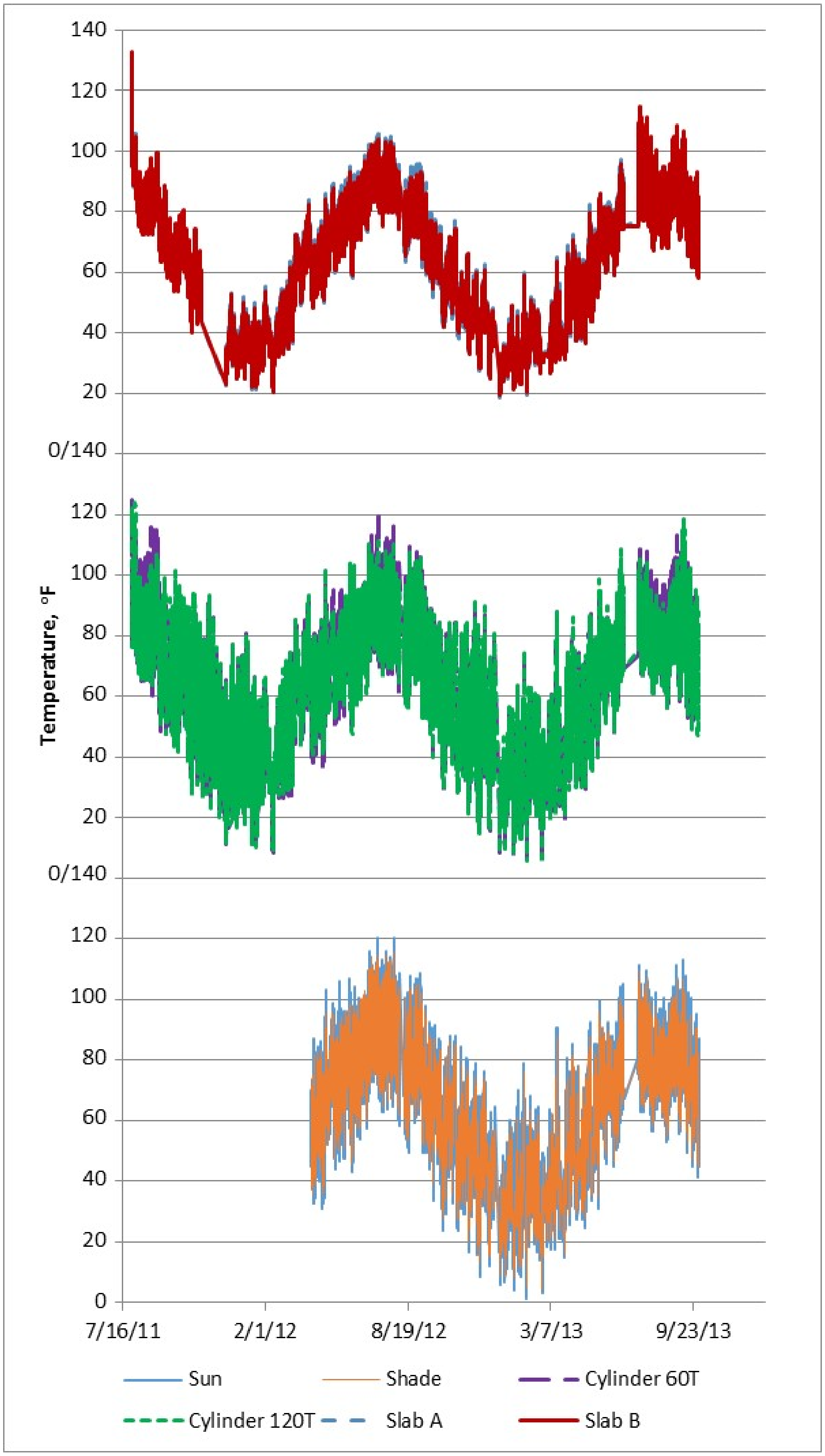

Figure 3.1b: Temperature vs. time for summer slab with 100% portland cement (PC) mixture (different range).

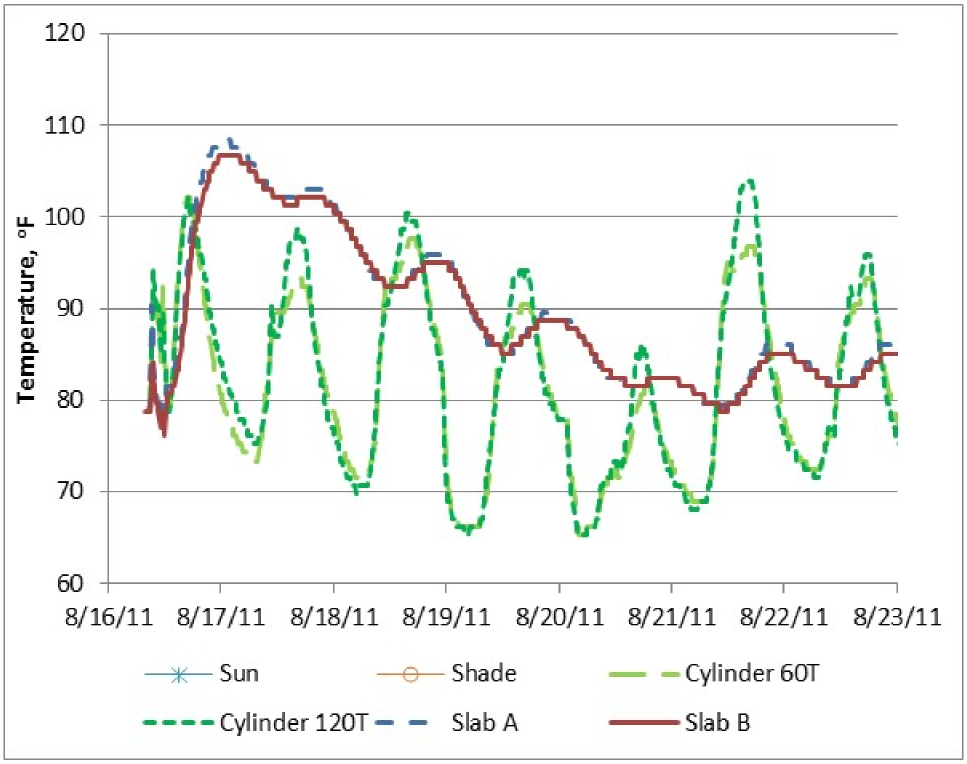

Figure 3.2a: Temperature vs. time for summer slab with 65% portland cement/35% slag (PC/S/FA) mixture.

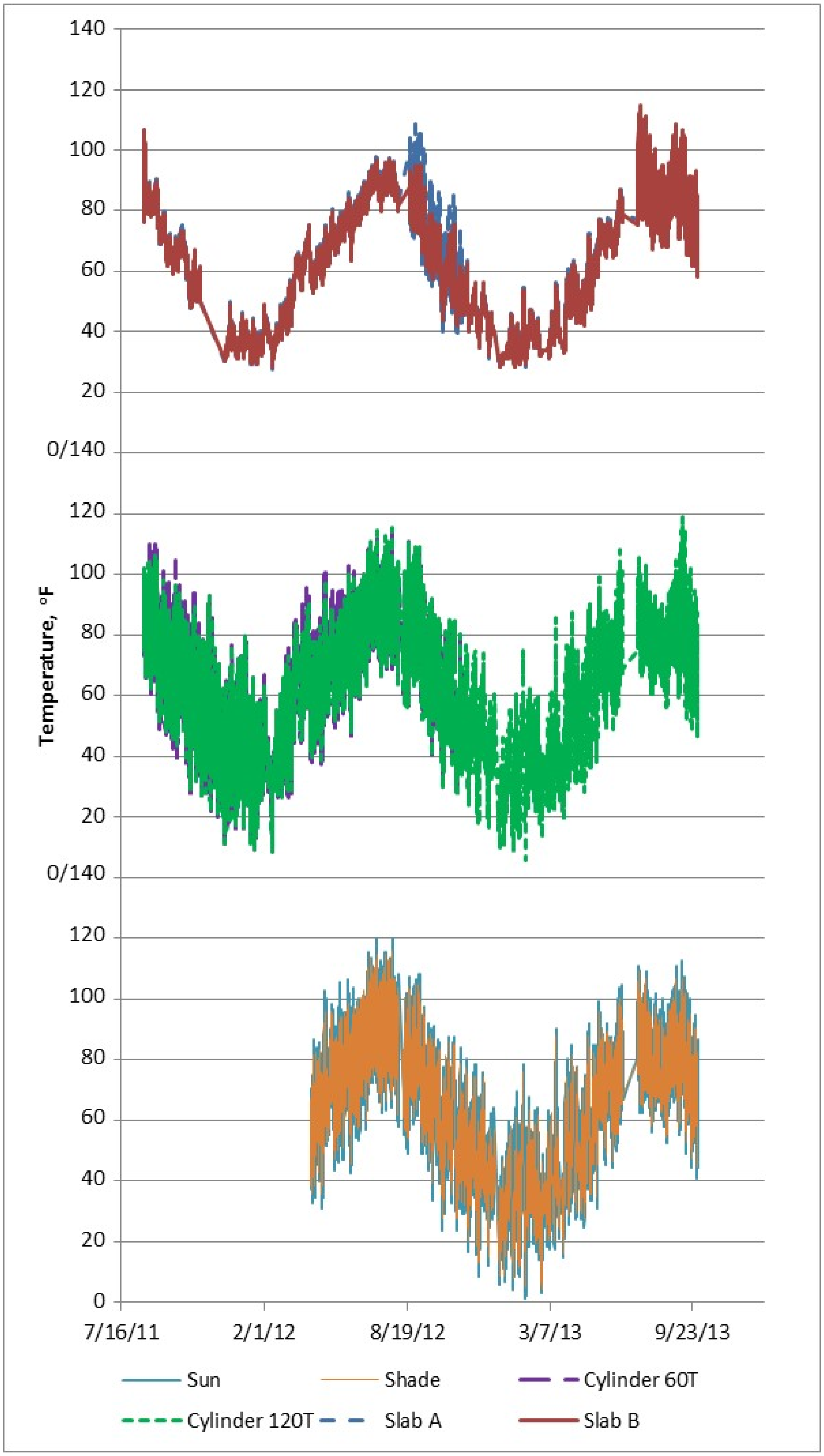

Figure 3.2b: Temperature vs. time for summer slab with 65% portland cement/35% slag (PC/S/FA) mixture (different range).

3.2 Strength Test Results

This section presents the compressive strength results for the mixtures. The plots show the average strengths of three cylinders (or cores), with the range of values obtained given by error bars. Differences in strength between cylinder types or cores were considered to be statistically significant if a Student's t-test between two sets of data showed the probability that the differences were due to natural variation (chance) was less than 10 percent ($p < 0.1$). The results of Student's t-test are summarized for each age of testing in Tables B.1 through B.6 in Appendix B. Additional comparisons based on strength are given in Tables B.19 through B.21 and B.28. Individual specimen data covering compressive strength and the boil and RCP tests are presented in Appendix C. As will be demonstrated below, the lab-cured cylinders were consistently stronger than the field-cured cylinders and cores.

3.2.1 100% Portland Cement (PC) Mixtures

The strength test results for the 100% portland cement (PC) mixture cast in the summer are shown in Figure 3.3. The lab-cured cylinders had the highest average strength at all ages, with values as high as 1000 psi greater than the field-cured cylinder and core strengths at 180 days (p = 0.014). As shown in Appendix A, however, the differences between the lab-cured cylinders and the other specimens were not consistently statistically significant, with no statistically significant differences with field-cured cylinders at 28, 56, 360, and 720 days, and no statistically significant differences with cores at 28 and 90 days. The field-cured cylinders and cores exhibited similar average strengths at all ages, with field-cured cylinders exhibiting slightly lower strengths than cores at all ages except for 360 days.

Compressive strengths tended to increase or hold steady from 28 to 720 days, with the exception of the 180-day compressive strengths, which showed statistically significant reductions for field-cured cylinders compared to 90-day strengths. Even the lab-cured specimens showed a slight drop in average strength from 5420 to 5220 psi. It is not known why this reduction occurred. The 28-day compressive strengths ranged from 4160 psi (for field-cured cylinders) to 4490 psi (for lab-cured cylinders), with the highest average strength, 5900 psi, observed in the lab-cured cylinders at 360 days.

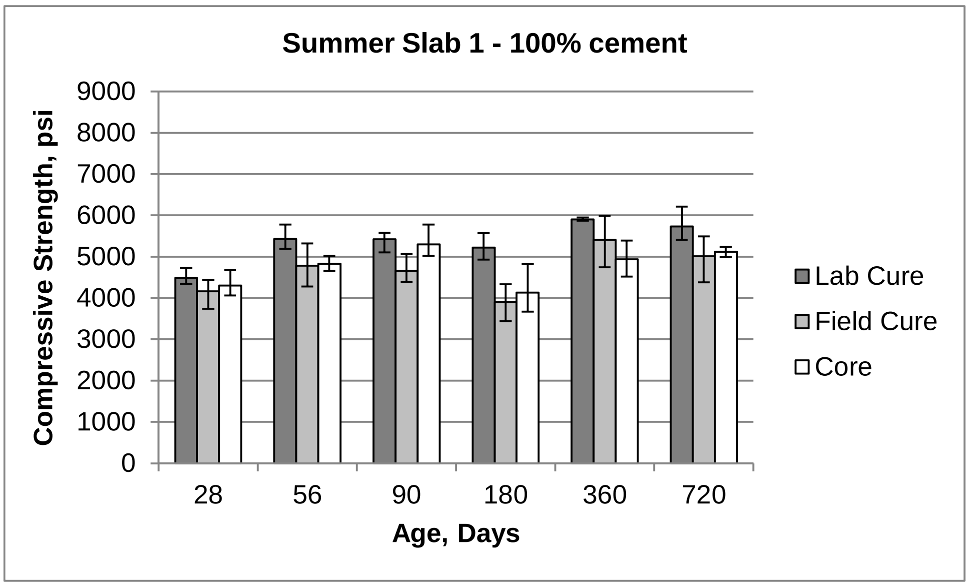

Figure 3.3: Compressive strengths for summer slab with 100% portland cement (PC) mixture.

The strength test results for the 100% portland cement (PC) mixture cast in the fall are shown in Figure 3.4. The lab-cured cylinders had the highest average strength at all ages, except for 720 days, where field-cured cylinders had the highest average strength, representing the only time that the lab-cured and field-cured cylinders exhibited a statistically significant difference in strength ($p = 0.070$). The cores consistently exhibited slightly lower strengths than the lab-cured or field-cured cylinders, but the only statistically significant difference was observed between the cores and lab-cured cylinders at 360 days ($p = 0.030$); the differences between core and cylinder strengths at other ages were not statistically significant ($p > 0.1$).

The compressive strengths tended to increase or hold steady from 28 to 720 days, with the exception of a slight drop in strength at 90 days for all samples, and at 720 days for the lab-cured cylinders. The slab exhibited higher compressive strengths than the summer slab with the 100% portland cement (PC) mixture, with 28-day compressive strengths between 4730 psi (field-cured cylinders) and 5230 psi (lab-cured cylinders), and the highest average strength, 7010 psi, observed in the field-cured cylinders at 720 days. This may be due to the better curing conditions in the fall or the slightly lower actual *w/cm* ratio in the fall slab with the 100% portland cement (PC) mixture (0.42) compared to the summer slab with the 100% portland cement (PC) mixture (0.43).

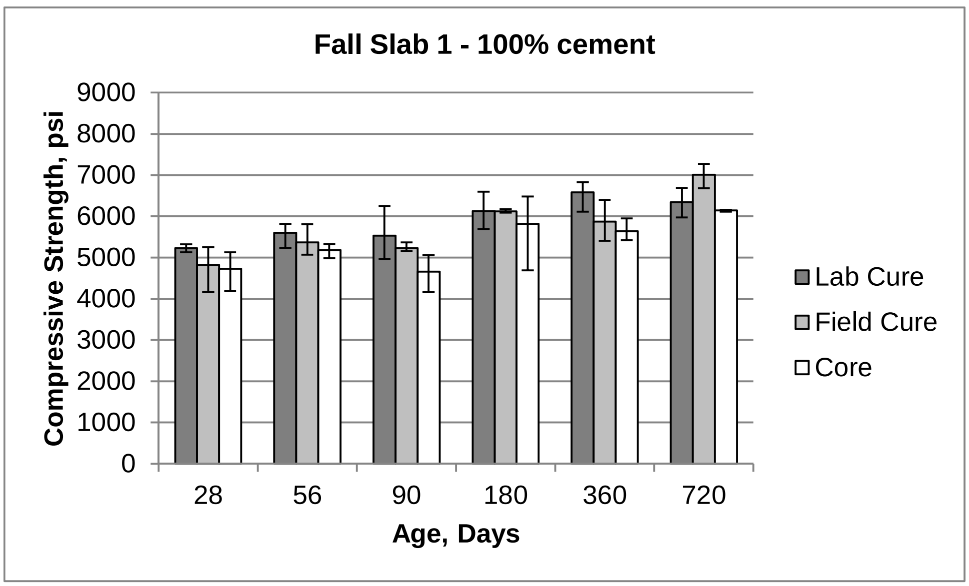

Figure 3.4: Compressive strengths for fall slab with 100% portland cement (PC) mixture.

The strength results for the 100% portland cement (PC) mixture cast in the springare shown in Figure 3.5. The lab-cured cylinders had the highest average strength at all ages, except at 28 days and 360 days, where field-cured cylinders and cores, respectively, had the highest average strength. The difference in strength between lab and field-cured cylinders was not statistically significant at any age, however. Cores exhibited lower strengths than lab-cured cylinders with differences that were statistically significant at 28 days (p = 0.033), lower strengths than field-cured cylinders with differences that were statistically significant at 28 days ($p = 0.034$), and higher strengths than field-cured cylinders with differences that were statistically significant at 180 days ($p = 0.013$) and 360 days ($p = 0.031$). The differences between core and cylinder strengths at other ages were not statistically significant ($p > 0.1$).

Compressive strengths generally increased from 28 to 360 days. A drop in strength was observed at 720 days. This may have been due to honeycombing in the cylinders; however, the drop in strength was also observed in the cores, which were free from honeycombing. Of the three 100% portland cement (PC) slabs, the spring slab exhibited the highest early compressive strength, with 28-day compressive strengths between 5760 psi (cores) and 6960 psi (field-cured cylinders), with the highest average strength, 8030 psi, observed in the cores at 360 days. This difference was statistically significant across lab-cured cylinders ($p < 0.0007$), field-cured cylinders ($p < 0.008$), and cores ($p < 0.06$). This is likely due to the concrete in the spring slab with the 100% portland cement (PC) mixture having a lower actual *w/cm* ratio (0.40) than the concrete in the summer (0.43) and fall (0.42) slabs, combined with the more optimal curing conditions experienced during the first week of curing.

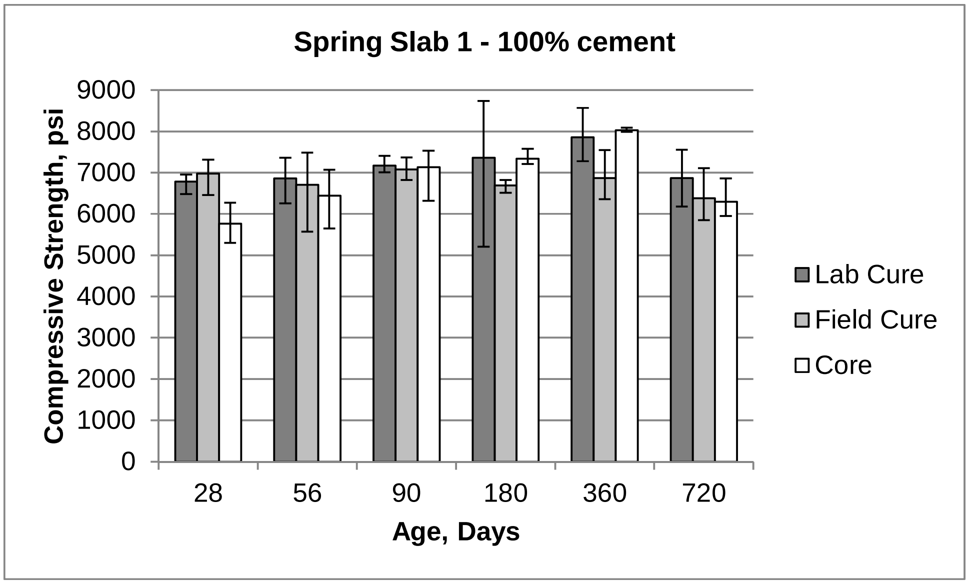

Figure 3.5: Compressive strengths for spring slab with 100% portland cement (PC) mixture.

3.2.2 65% Portland Cement/35% Slag (PC/S) Mixtures

As with the 100% portland cement mixtures, the lab-cured cylinders for the 65% portland cement/35% slag mixtures exhibited higher strength that the field-cured cylinders and cores in most cases, but unlike the 100% portland cement mixtures, the differences were statistically significant in many cases (slab at 28, 56, 90, 180 and 720 days for field-cured cylinders and at 56, 90, 180, and 720 days for cores; fall slab at 90 and 180 days for field-cured cylinders; spring slab at 90 and 180 days for field-cured cylinders and 90, 180 and 360 days for cores - see in Appendix A).

The strength test results for the 65% portland cement/35% slag mixture cast in the summer are shown in Figure 3.6. The lab-cured cylinders had the highest average strength at all ages, except for 56 days, where cores had the highest average strength. The difference in strength between lab and field-cured cylinders was statistically significant ($p < 0.1$) at all ages, except 360 days; the difference between lab-cured cylinders and cores was statistically significant at 90, 180, and 720 days. The field-cured cylinders consistently exhibited lower strengths than the cores, but the differences between core and field-cured cylinder strengths were only statistically significant ($p <$ 0.04) at 56, 90, and 180 days.

The concrete in the summer slab with the 65% portland cement/35% slag (PC/S/FA) mixture exhibited 28-day compressive strengths between 4630 psi (field-cured cylinders) and 5610 psi (lab-cured cylinders), with the highest average strength, 6750 psi, observed in the lab-cured cylinders at 360 days.

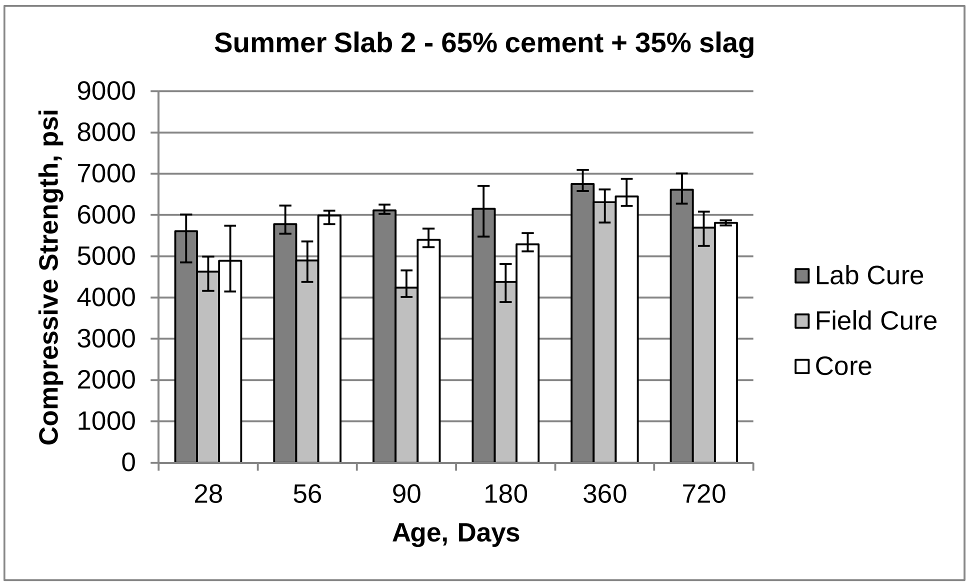

Figure 3.6: Compressive strengths for summer slab with 65% portland cement/35% slag (PC/S/FA) mixture.

The strength test results for the 65% portland cement/35% slag mixture cast in the fall are shown in Figure 3.7. The lab-cured cylinders had the highest average strength at 56, 90, and 180 days; the differences in strength were statistically significant at 90 and 180 days. The cores had the highest average strength at 360 and 720 days, and the field-cured cylinders had the highest strength at 28 days, although the differences in strength at 28 days were not statistically significant ($p > 0.5$).

Compressive strengths tended to increase or hold steady from 28 to 180 days. A drop in strength in the lab and field-cured cylinders was observed at 360 and 720 days, although the change in strength was not statistically significant ($p > 0.28$). During this time, the core strengths continued to increase. The fall slab exhibited somewhat higher strengths than the summer slab (despite having a slightly higher actual *w/cm* ratio, 0.42 vs. 0.41), with 28-day compressive strengths between 5450 psi (lab-cured cylinders) and 5690 psi (field-cured cylinders). However, only the field-cured cylinders showed a statistically significant difference ($p = 0.029$) between the summer and fall slabs at 28 days. This somewhat higher strength may be due to the more moderate casting and curing temperatures experienced by the fall slab. The highest average strength, 7960 psi, was observed in the cores at 720 days.

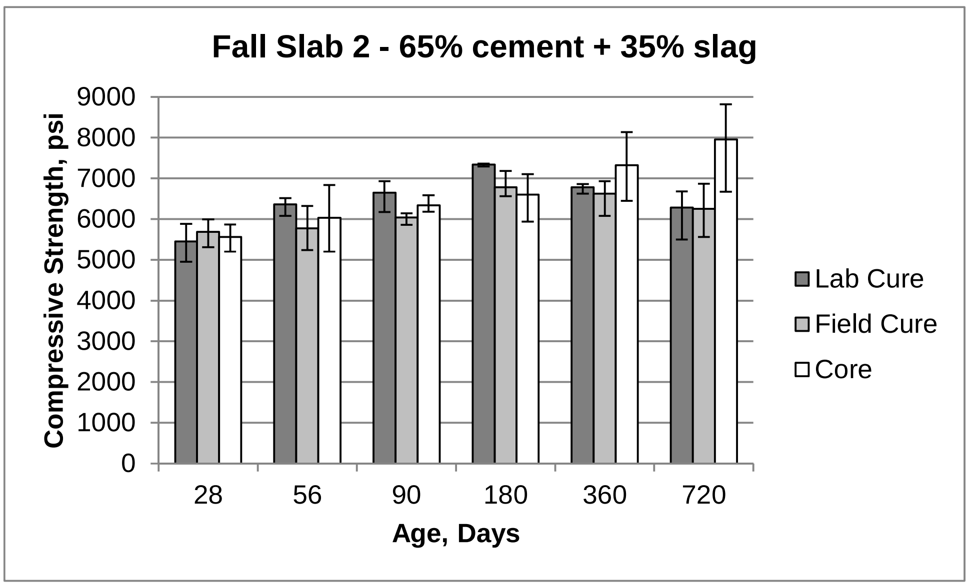

Figure 3.7: Compressive strengths for fall slab with 65% portland cement/35% slag (PC/S/FA) mixture.

The strength test results for the 65% portland cement/35% slag mixture cast in the spring are shown in Figure 3.8. The lab-cured cylinders had the highest average strength at all ages, except for 360 days, where cores had the highest average strength. The difference between field-cured cylinders and cores at 360 days was statistically significant ($p = 0.022$), but difference between lab-cured cylinders and cores was not ($p = 0.407$). The greatest variations in strength between lab-cured cylinders and other specimens were observed at 90 and 180 days, with the lab-cured cylinders being stronger than field-cured cylinders and cores with differences that were statistically significant ($p < 0.013$).

Compressive strengths tended to increase or hold steady from 28 to 720 days. The cores showed over a 10% jump in compressive strength between 180 and 360 days; dropping at 720 days to strengths that were similar to the 180-day core strengths. The spring lab exhibited strengths similar to the fall slab, with 28-day compressive strengths between 5270 psi (field-cured cylinders) and 6130 psi (lab-cured cylinders) and the highest average strength of 7470 psi observed in the cores at 360 days.

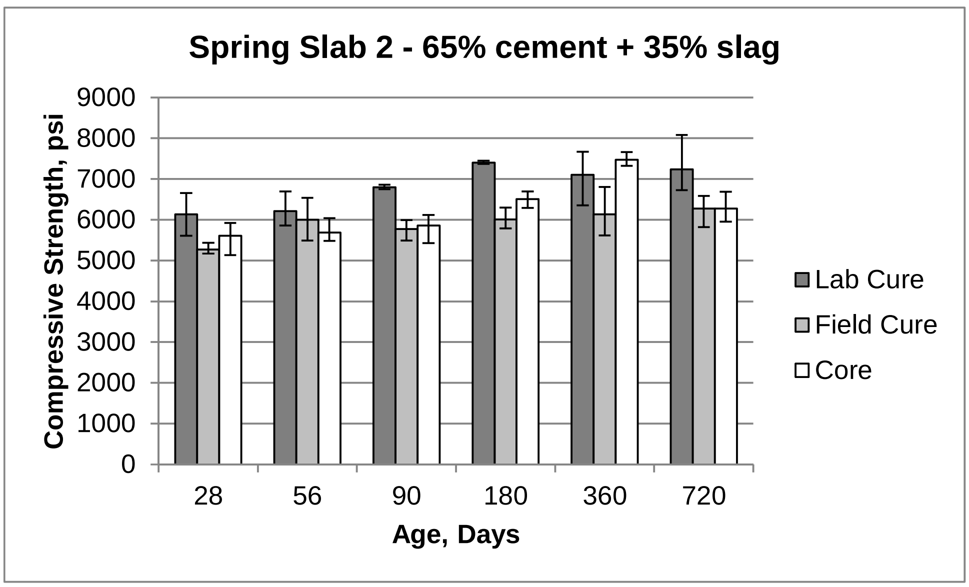

Figure 3.8: Compressive strengths for spring slab with 65% portland cement/35% slag (PC/S/FA) mixture.

3.2.3 60% Portland Cement/25% Slag/15% Class C Fly Ash (PC/S/FA) Mixtures

As with the 100% portland cement and 65% portland cement/35% slag mixtures, the lab-cured cylinders exhibited higher compressive strengths than the field-cured cylinders and cores for the 60% portland cement/25% slag/15% Class C fly ash mixtures. The differences were statistically significant for the summer slab with the 60% portland cement/25% slag/15% Class C fly ash mixture at all ages for the field-cured cylinders and at 90 and 180 days for the cores; for the fall slab at 56 and 90 days for the field-cured cylinders and at 90 days for the cores; and for the spring slab at 56 and 180 days for the field-cured cylinders.

The strength test results for the 60% portland cement/25% slag/15% Class C fly ash mixture cast in the summer are shown in Figure 3.9. The lab-cured cylinders had the highest average strength at all ages, except at 28 days, where cores had 0.2% greater strength.

The compressive strengths for the lab and field-cured cylinders tended to increase or hold steady from 28 to 720 days. The core strengths declined slightly from 28 to 180 days (by 8%), but then gained strength at 360 and 720 days. The concrete in the slab exhibited 28-day compressive strengths between 4070 psi (field-cured cylinders) and 5160 psi (lab-cured cylinders). The highest average strength, 6750 psi, was observed in the lab-cured cylinders at 360 days.

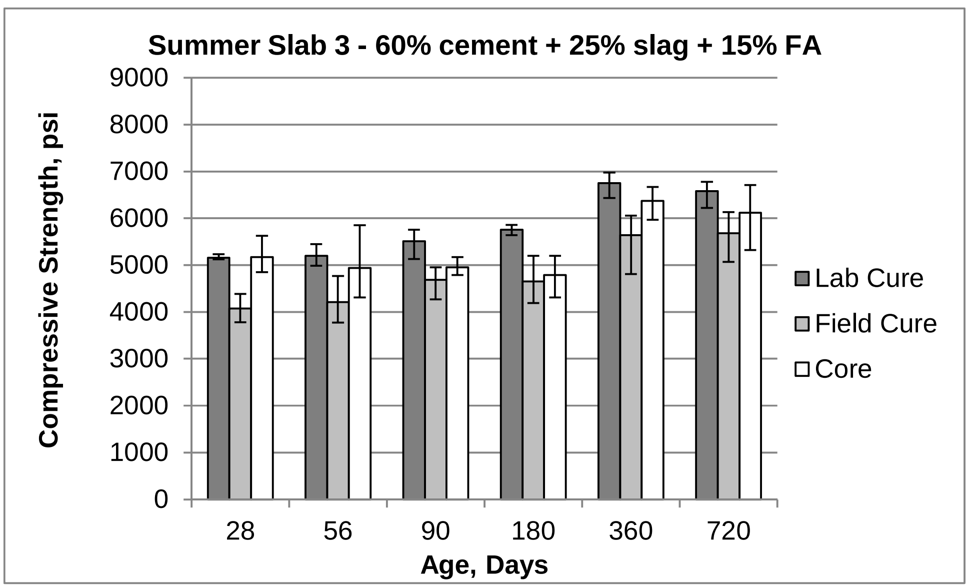

Figure 3.9: Compressive strengths for summer slab with 60% portland cement/25% slag/15% Class C fly ash (PC/S/FA) mixture.

The strength test results for the 60% portland cement/25% slag/15% Class C fly ash mixture cast in the fall are shown in Figure 3.10. The lab-cured cylinders had the highest average strength through 90 days, although the differences in strength between cylinders and cores were not statistically significant at 28 days. After 90 days, cores had the highest average strength, although this difference was also not statistically significant. Except at 360 days, the field-cured cylinders exhibited the lowest compressive strengths at all ages.

Compressive strengths tended to increase or hold steady from 28 to 720 days for the field-cured cylinder and core tests. The lab-cured cylinders showed a decrease in strength between 90 and 360 days, but then gained significant strength (29%) between 360 and 720 days. The slab exhibited 28-day compressive strengths between 3490 psi (field-cured cylinders) and 4410 psi (lab-cured cylinders), the lowest of any slab. This difference was statistically significant ($p <$ 0.0230 for all comparisons, except for the comparison between field-cured cylinders for the fall and summer slabs). The highest average strength, 6210 psi, was observed in the cores at 720 days.

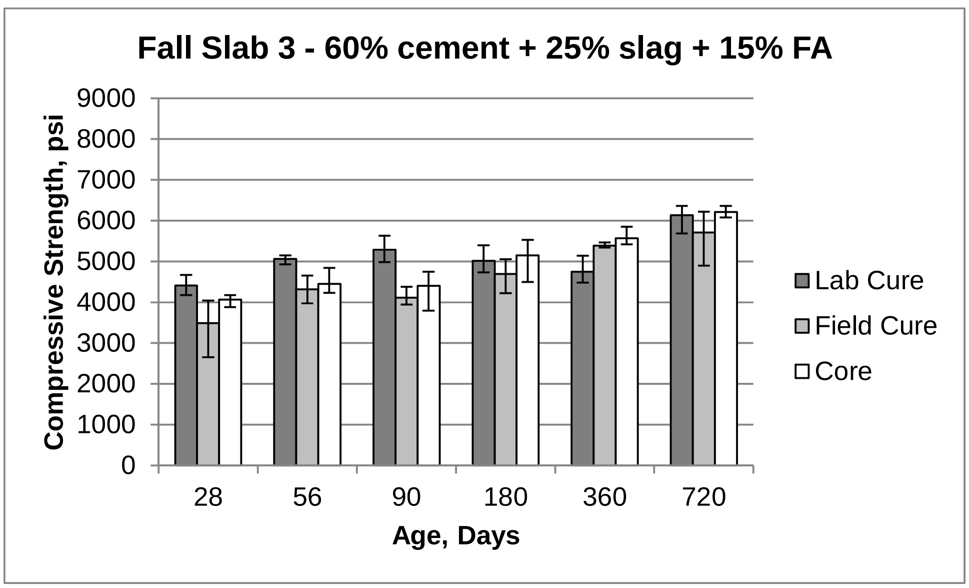

Figure 3.10: Compressive strengths for fall slab with 60% portland cement/25% slag/15% Class C fly ash (PC/S/FA) mixture.

The strength test results for the 60% portland cement/25% slag/15% Class C fly ash (PC/S/FA) mixture cast in the spring are shown in Figure 3.11. The lab-cured cylinders had the highest average strength at all ages, except at 720 days, where the field-cured cylinders had a slightly higher average strength. The differences in strength between lab-cured cylinders and field-cured cylinders were statistically significant at 56 and 180 days. The differences in strength between lab-cured cylinders and cores were not statistically significant.

Compressive strengths tended to increase or hold steady from 28 to 720 days. The concrete in the slab exhibited 28-day compressive strengths between 5120 psi (field-cured cylinders and cores) and 5490 psi (lab-cured cylinders). The highest average strength, 7460 psi, was observed in the field-cured cylinders at 720 days.

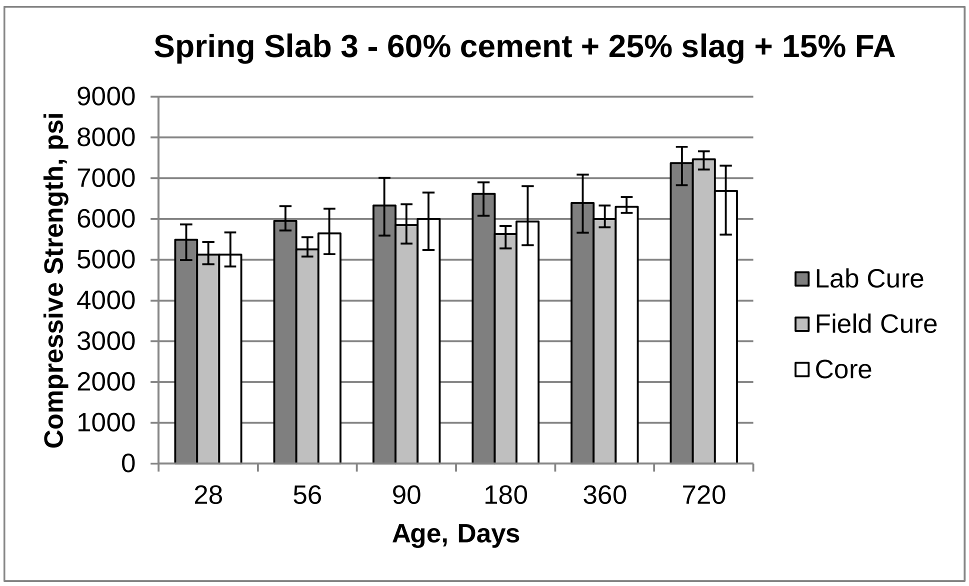

Figure 3.11: Compressive strengths for spring slab with 60% portland cement/25% slag/15% Class C fly ash (PC/S/FA) mixture.

3.2.4 Comparison of Compressive Strengths

3.2.4.1 Comparison between Cylinders and Cores

Figure 3.12a shows the ratio of average field-cured cylinder strength to average lab-cured cylinder strength for all slabs at all ages. A ratio less than 1.0 indicates that the strength of the field-cured cylinders was less than the strength of the lab-cured cylinders. The overall average is 0.898, with the lab-cured cylinders stronger than field-cured cylinders in 91% of the cases. This effect is most prominent in the slabs that experienced very hot temperatures (summer slabs) or very cold temperatures (Fall Slab, 60% PC/25% S/15%FA) at early ages. The summer and fall slabs with 60% PC/25% S/15% FA had field-cured cylinders with strengths more than 20% less than the field-cured cylinders at 28 days. The only slabs with lab-cured cylinder strengths less than the corresponding field-cured cylinder strengths at 28 days were the fall slab with 65%PC/35% S and the spring slab with 100% PC. In both cases, the difference between lab and field-cured cylinder strengths at 28 days was less than 5%.

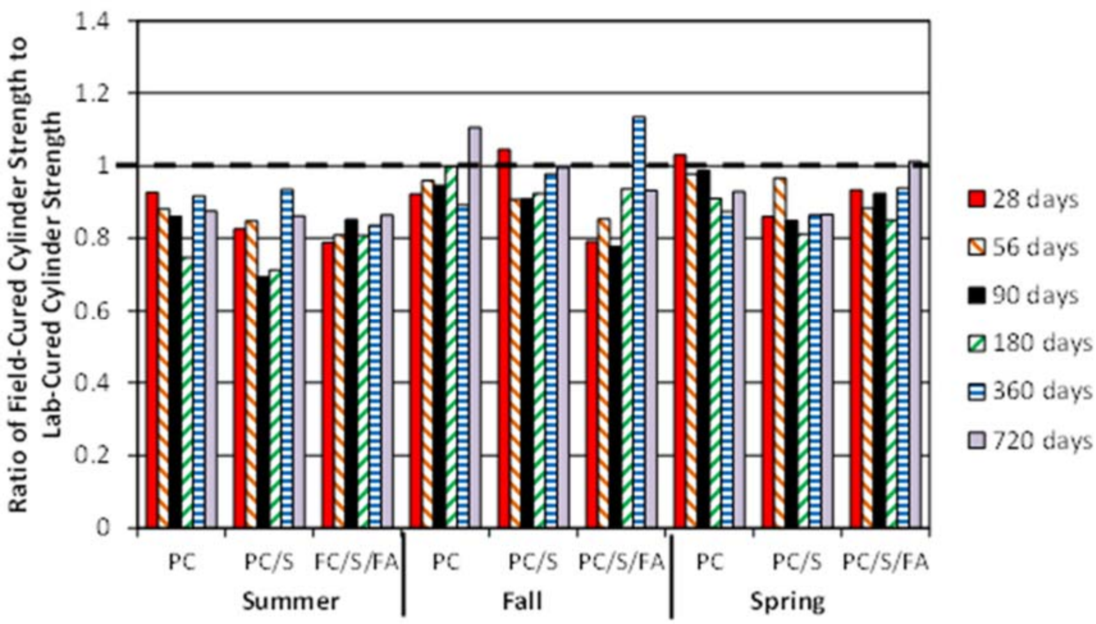

Figure 3.12a: Ratio of field-cured to lab-cured cylinder strength.

Figure 3.12b shows the ratio of average core strength to average lab-cured cylinder strength for all slabs at all ages. A ratio less than 1.0 indicates that the strength of the slab as measured by core samples was less than the strength obtained from lab-cured cylinders. The overall average is 0.939. As shown in Figure 3.12b, core strengths were less than lab-cured cylinder strengths in the vast majority of cases (81% of all data points). This effect is especially evident at early ages; in the first 90 days, the only specimens to exhibit ratios above 1.0 were the summer slab with 65% PC/35% S at 56 days and the fall slab with 65% PC/35% S at 28 days, and in both cases, the cylinder strengths were within 5% of the core strengths. In the case of the fall slab with 60% PC/25% S/15% FA, which was exposed to the coldest early age conditions (with several subfreezing days in the first week of curing), the lab-cured cylinders averaged strengths as high as 20% greater than the cores at 90 days. For tests at ages greater than 90 days, average cylinder strengths still exceeded the core strengths except for the fall slab with 65% PC/35% S at 360 and 720 days, the fall slab with 60% PC/25% S/15% FA at ages greater than 90 days, and the spring slabs with 100% PC and 65% PC/35% S at 360 days.

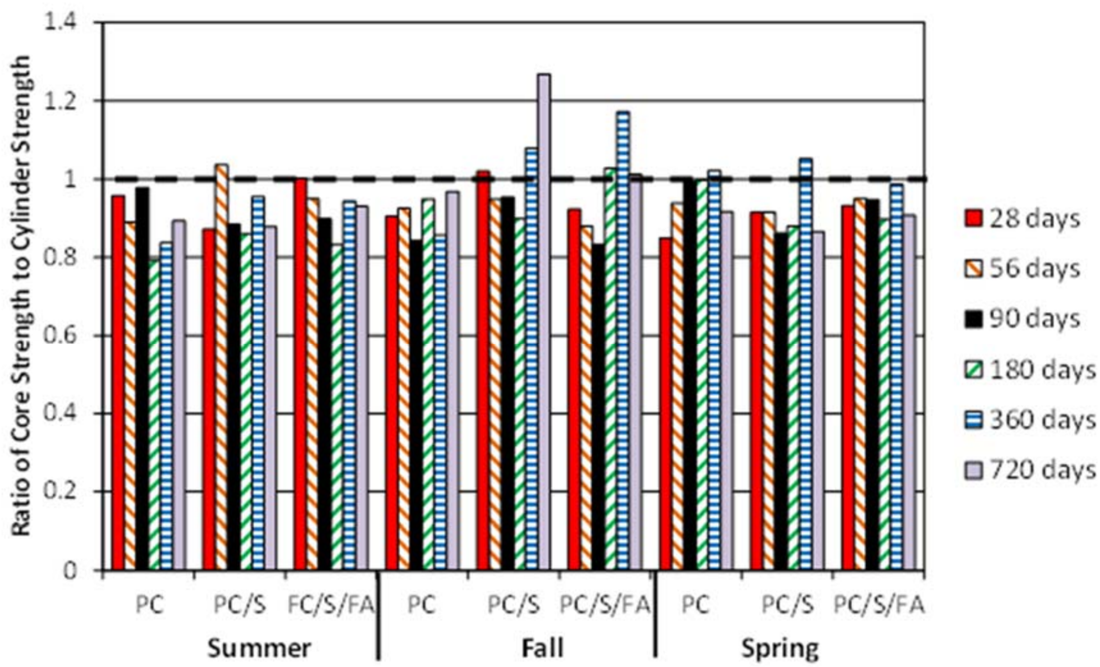

Figure 3.12b: Ratio of core strength to lab-cured cylinder strength.

Figure 3.12c shows the ratio of average core strength to average field-cured cylinder strength for all slabs at all ages. Unlike the comparison with lab-cured cylinders, core strengths were greater than field-cured cylinder strengths in most cases (76% of all data points) (overall average of 1.05). This effect was persistent across all ages and temperature ranges. As shown in Appendix A, the low thermal mass of the cylinders resulted in their experiencing greater variations in temperature than the slabs, which likely impacted their strength. The only slab to consistently exhibit ratios of core strength to cylinder strength less than 1.0 was the fall slab with 100% PC. This may be due to the temperature during the first week after casting, which, although varying, averaged close to 70 °F and was close to ‘lab-cured’ conditions. The average field-cured cylinder strength exceeded the average core strength in just 13 out of 54 cases, including the summer slab with 100% PC at 28 days, the fall slab with 100% PC for all ages, the fall slab with 65%PC/35% S for 28 and 180 days, the spring slab with 100% PC for 28 and 56 days, The spring slab with 65% PC/35% S for 56 days, and the spring slab with 60% PC/25% S/15% FA for 720 days.

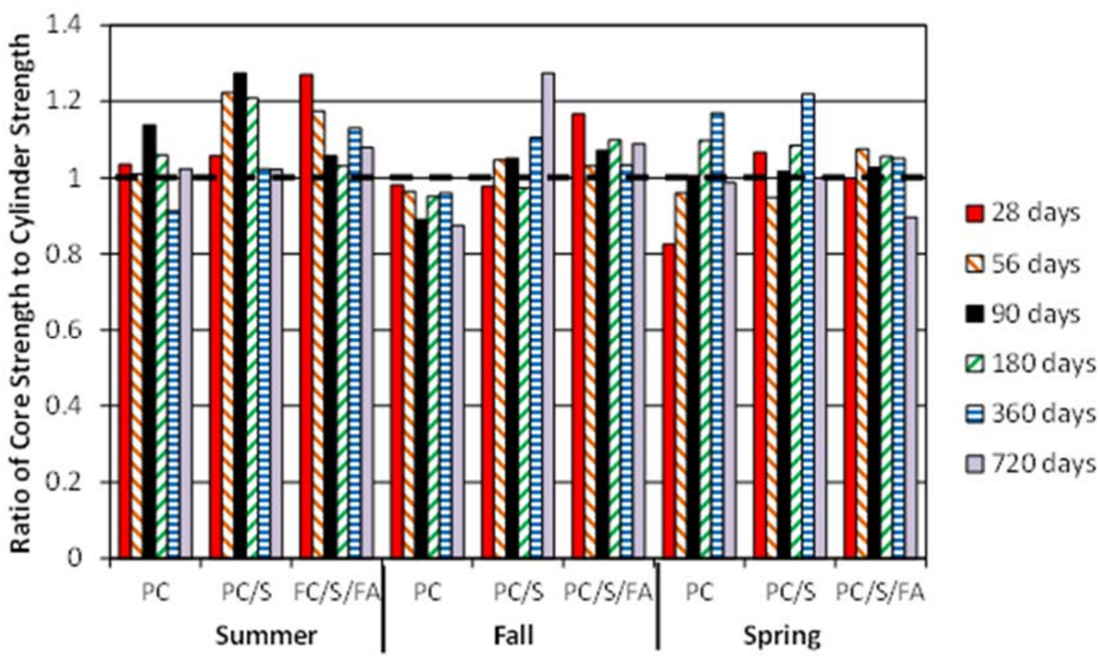

Figure 3.12c: Ratio of core strength to field-cured cylinder strength.

To establish the statistical significance of the differences observed between lab-cured cylinders, field-cured cylinders, and cores, Student’s t-test was performed for all possible pairings of specimens. Comparisons were made between average values at a given age from each slab. Differences between cylinder types and cores were considered statistically significant if the Student’s t-test returned values of α less than 0.10.

Table 3.1 shows the summary of the Student's t-test comparisons based on strength. Individual comparisons are presented in Tables B.1 through B.6 in Appendix B. In 40.7% of the comparisons, lab-cured cylinders were stronger than the field-cured cylinders from the same slab at the same age with differences in strength that were statistically significant, while only 3.7% of field-cured specimens were similarly stronger than the lab-cured cylinders. This difference was in all likelihood due to the better curing conditions (availability of water and controlled temperature range) for the lab-cured cylinders. When comparing lab-cured specimens and cores, 27.8% of lab-cured cylinders were stronger than the cores from the same slab at the same age with differences in strength that were statistically significant, whereas only 3.7% of cores were similarly stronger than the lab-cured cylinders. The field-cured cylinders and cores showed the smallest percentage of statistically significant differences in strength; 3.7% of field-cured cylinders were stronger than the cores from the same slab at the same age with differences in strength that were statistically significant, while 16.7% of cores were similarly stronger than the field-cured. The field-cured cylinders dry out more rapidly than either the lab-cured cylinders or the slab, explaining the lower strength.

In the majority of cases, the individual differences between strengths were not statistically significant. The large majority of cases, however, in which the strength of lab-cured cylinders exceeded the strength of cores and field-cured cylinders and the strength of cores exceeded the strength of field-cured cylinders indicates that these differences are consistent and should be expected in practice.

Table 3.1: Percentage of Specimens with Statistically Significant Strength Differences

Comparison	Percentage of Specimens
Lab vs. Field	
Lab-cured cylinder stronger	40.7%
Field-cured cylinder stronger	3.7%
Difference not statistically significant	55.6%
Lab vs. Core	
Lab-cured cylinder stronger	27.8%
Core stronger	3.7%
Difference not statistically significant	68.5%
Field vs. Core	
Field-cured cylinder stronger	3.7%
Core stronger	16.7%
Difference not statistically significant	79.6%

3.2.4.2 Effect of Season

Figures 3.13, 3.14, and 3.15 show the average compressive strengths for the cores from slabs with 100% portland cement (PC); 65% portland cement/35% slag (PC/S); and 60% portland cement/25% slag/15% Class C fly ash (PC/S/FA) mixtures, respectively. Lab-cured and field-cured specimens show similar trends.

For the slabs with 100% portland cement (PC) (Figure 3.13), the summer slab had the lowest average core strength at all ages except for 90 days. The concrete temperature at placement for the summer slab (90 °F) was significantly higher than the temperatures for the fall or spring slabs (66 °F and 72 °F, respectively); the higher initial temperature and higher early curing temperatures likely negatively affected the strength. The summer slab with 100% PC, however, also had a higher actual *w/cm* ratio (0.43) than the slabs with the same mixture cast in the fall (0.42) or spring (0.40), which contributed to the lower strength. The spring slab had the highest average strength at all ages, despite the concrete temperature being close to that of the fall slab. It is possible that the cold winter slowed the strength gain of the fall slab. The actual *w/cm* ratio for the spring slab (0.40) was the second lowest for all slabs, with only the fall slab with 60% PC/25% S/15% FA having a lower ratio (0.39).

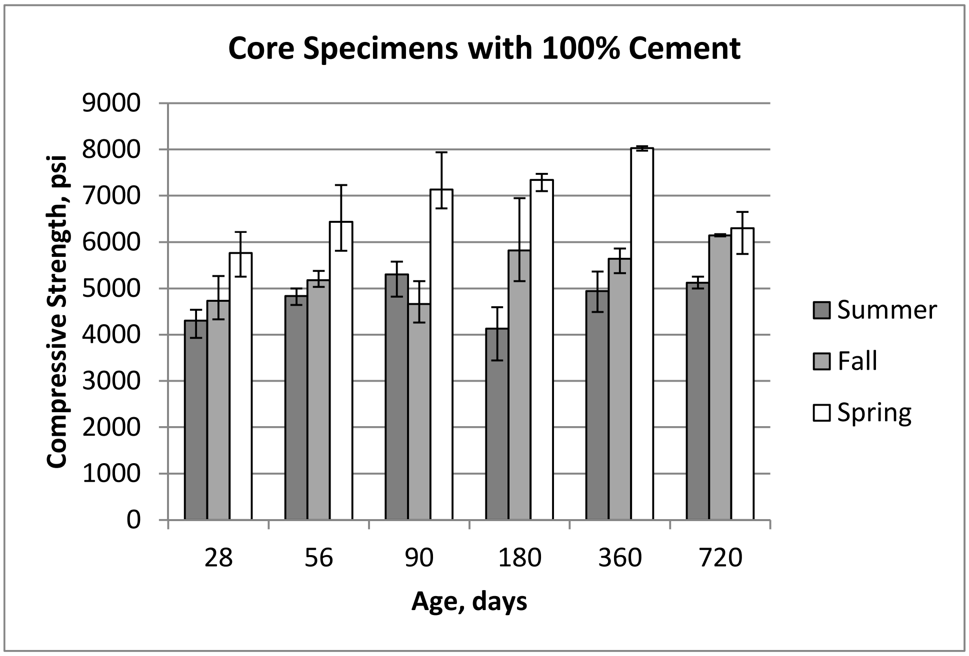

Figure 3.13: Compressive strengths (psi) for cores from slabs with 100% portland cement (PC).

For the slabs with the 65% portland cement/35% slag mixture (Figure 3.14), much less variation in strength was observed between seasonal averages than observed for the 100% portland cement slabs, which had actual *w/cm* ratios of 0.41, 0.42, and 0.40 for the summer, fall, and spring slabs, respectively. Like the summer slab with 100% PC, the summer slab with 65% PC/35% S again had the highest concrete temperature at the time of placement (81º F) of the three slabs for this combination of cementitious materials and the lowest average core strength for all ages, except 56 days, where the spring slab with 65% PC/35% S had the lowest average strength. This occurred even though the summer slab with 65% PC/35% S had a lower *w/cm* ratio than the fall slab with the same mixture, which not only had the highest *w/cm* ratio but also had the *highest* core strength of the three slabs at 56, 90, 180, and 720 days, suggesting that the curing conditions played a key role in strength gain. The range in concrete temperature at the time of casting for these slabs (64 to 81º F) was lower than for the slabs containing 100% portland cement (PC) mixtures (66 to 90º F), however. The lower variation in concrete temperature may explain the lower variation in core strength for the slabs with the 65% portland cement/35% slag mixtures compared to the slabs with the 100% portland cement (PC) mixtures; it is also possible that the lower heat of hydration of slag makes the mixtures less susceptible to the detrimental effects of high temperature.

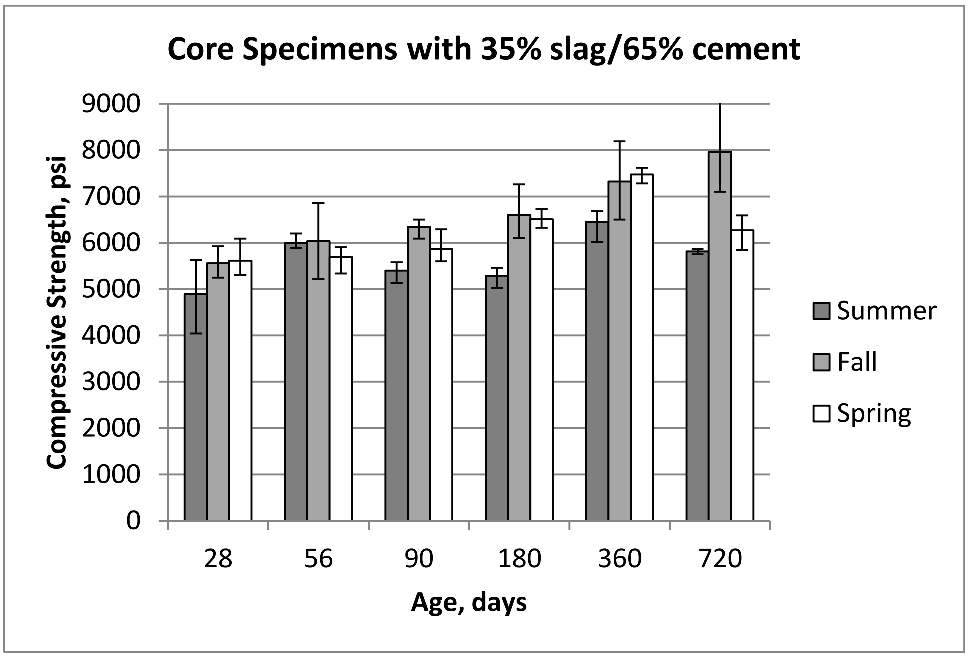

Figure 3.14: Compressive strengths (psi) for cores from slabs with 65% portland cement/35% slag (PC/S).

Slabs with the 60% portland cement/25% slag/15% Class C fly ash (PC/S/FA) mixture (Figure 3.15) had actual *w/cm* ratios of 0.42, 0.39, and 0.42 for the summer, fall, and spring slabs, respectively. Like the 65% portland cement/35% slag slabs, they also show much less variation in average strength between seasons than the 100% portland cement (PC) slabs. The fall slab with 60% PC/25% S/15% FA had the lowest average core strength for all ages, except 180 and 720 days, for which the summer slab had the lowest average strengths. The fall slab had the lowest concrete temperature at casting (54 °F), and the temperature after casting was frequently below freezing (Figure 3.9), but this slab also had the lowest *w/cm* ratio of any slab. Although the lower temperatures adversely affected the early age strength, after 180 days the slab exhibited similar strengths to the specimens cast in warmer weather. The summer and spring slabs with 60% PC/25% S/15% FA had similar concrete casting temperatures (86 °F and 83 °F, respectively) and exhibited similar strengths throughout testing, although the spring slab had the highest core compressive strength at 720 days.

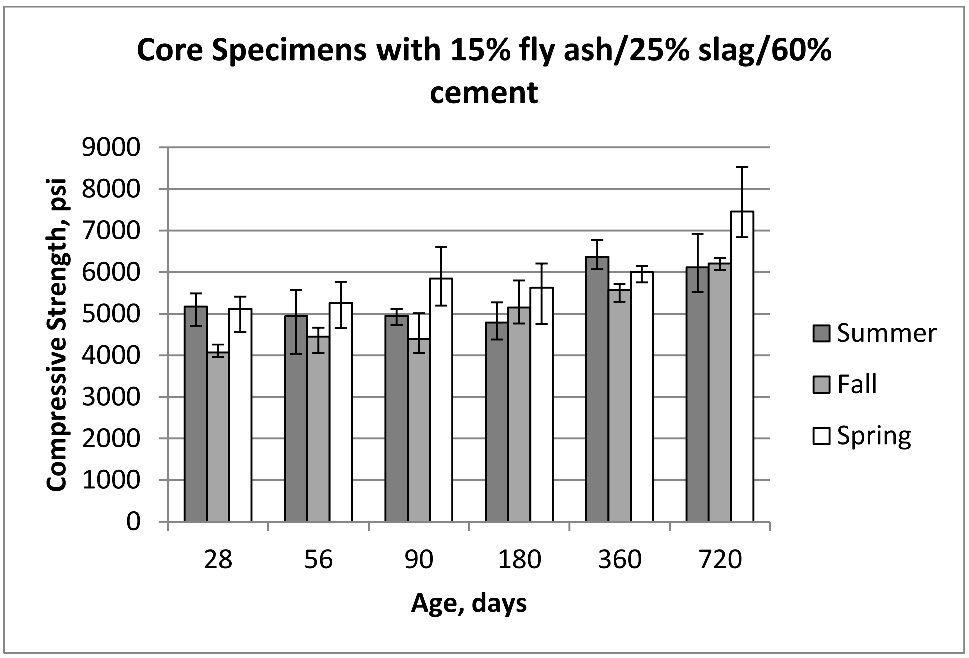

Figure 3.15: Compressive strengths (psi) for cores from slabs with 60% portland cement/25% slag/15% Class C fly ash (PC/S/FA).

3.2.4.3 Effect of Supplementary Cementitious Materials (SCMs)

Figures 3.16, 3.17, and 3.18 show the average compressive strengths of cores from slabs cast in the summer, fall, and spring, respectively. Trends from lab-cured and field-cured cylinders are similar. In the summer slabs (Figure 3.16), the slab with the 100% portland cement (PC) mixture had the lowest average core strength at all ages, except at 90 days; however, it was also the mixture with the highest concrete temperature at the time of casting [90 °F vs. 81 °F and 86 °F for the summer slabs with 65% PC/35% S and 60% PC/25% S/15% FA] and the highest actual *w/cm* ratio (0.43 vs. 0.41 and 0.42, respectively). The highest average core strength varied between the two mixtures containing supplemental cementitious materials. All three mixtures reached the target 28-day strength of 4000 psi.

Of the fall slabs (Figure 3.17), the slab with 65% PC/35% S had significantly higher compressive strengths than the other two fall slabs, despite having a higher actual *w/cm* ratio (0.42) than the fall slab with 60% PC/25% S/15% FA (0.39) and the same *w/cm* ratio as the slab with 100% PC. The fall slab with 65% PC/25% S/15% FA exhibited low early strengths (660 psi less than the slab with 100% PC and 1490 psi less than the slab with 65% PC/35% S), possibly due to subfreezing weather experienced for several days after casting. The compressive strength of the cores from this slab still exceeded the 4000 psi specified strength at 28 days, and long-term strengths were within 2% of the fall slab with 100% PC.

For the specimens cast in the spring (Figure 3.18), the slab with the 100% PC mixture, which had the same *w/cm* ratio as the slab with the 65% PC/35% S mixture, 0.40, had the highest strength at all ages, except 720 days. The slab with 60% PC/25% S/15% FA had a *w/cm* of 0.42.

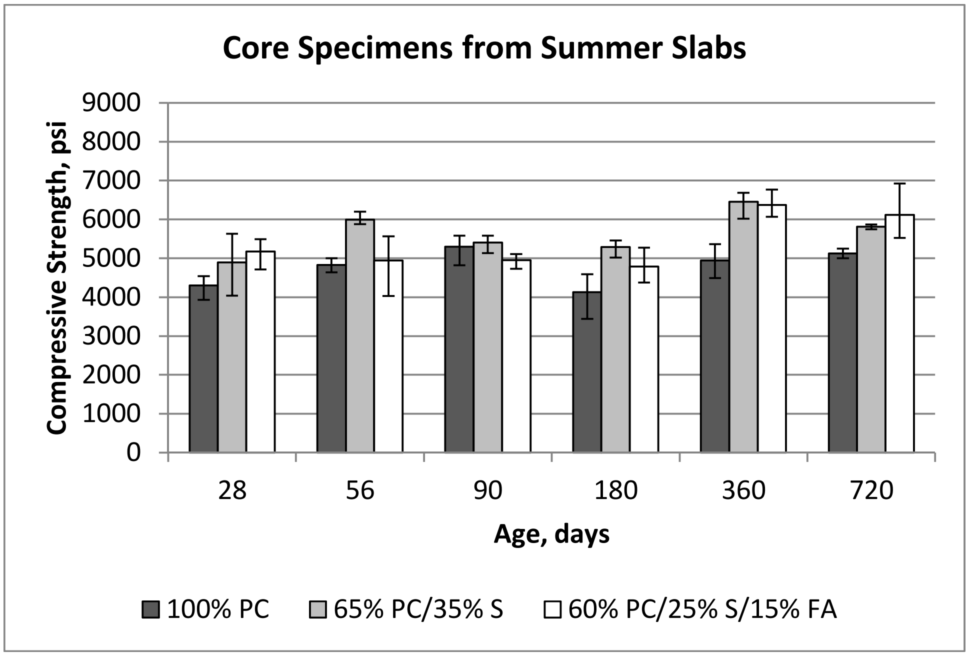

Figure 3.16: Compressive strengths (psi) for cores from slabs cast in the summer.

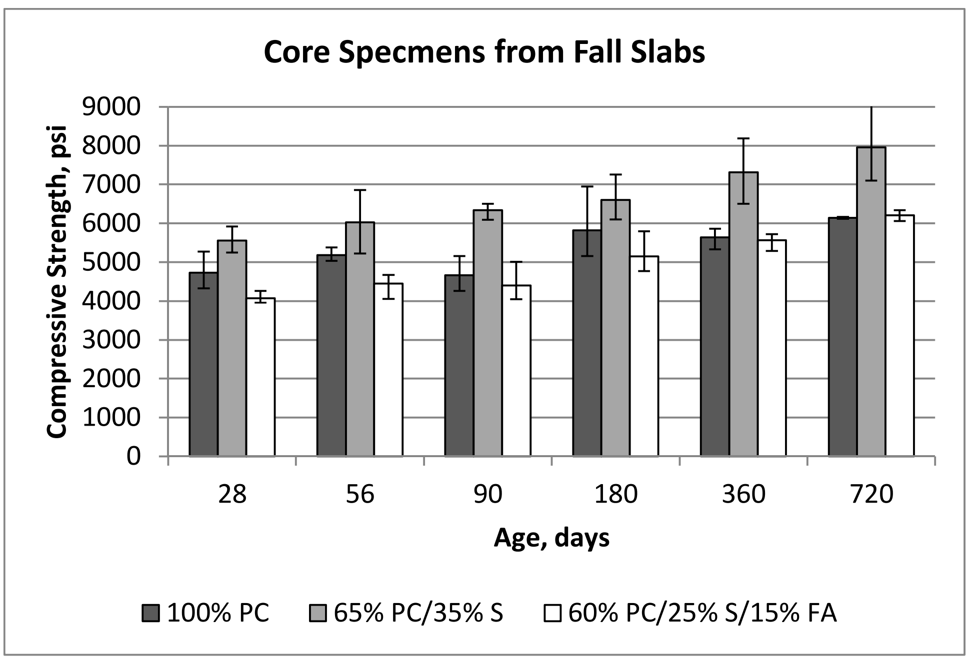

Figure 3.17: Compressive strengths (psi) for cores from slabs cast in the fall.

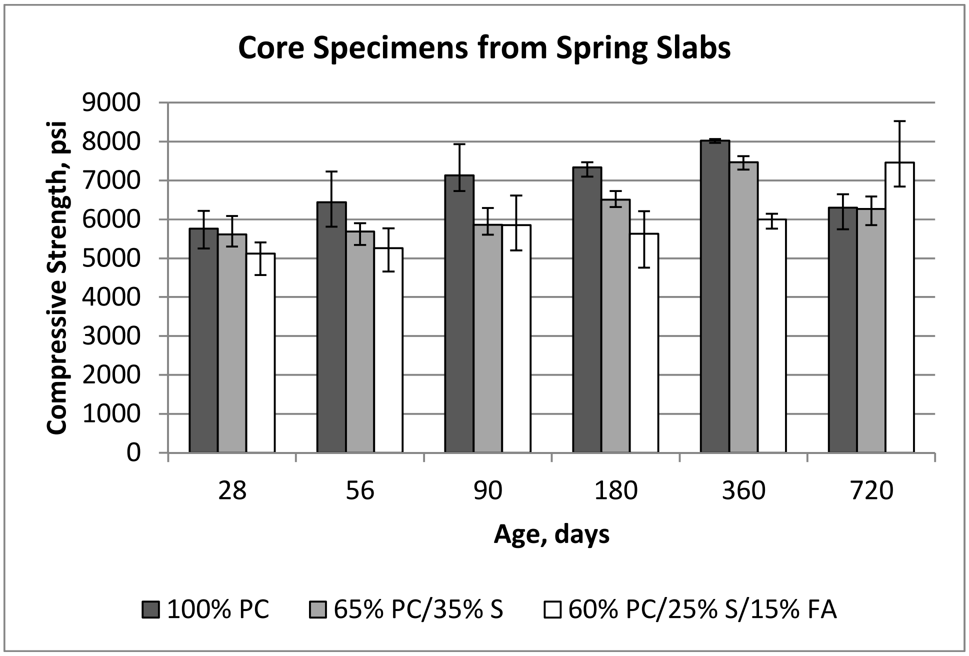

Figure 3.18: Compressive strengths (psi) for cores from slabs cast in the spring.

Figures 3.19a, 3.19b, and 3.19c show the changes in strength with time normalized to 28-day compressive strength for lab-cured cylinders, field-cured cylinders, and cores, respectively. The strengths presented are averaged across all seasons. For the lab-cured cylinders (Figure 3.19a), all mixtures had similar gains in strength through 90 days. The 100% PC mixture increased in strength through 360 days followed by a decrease in strength at 720 days. The 65% PC/35% S mixture increased in strength through 180 days, decreasing in strength at 360 days and again at 720 days. The 60% PC/25% S/15% FA mixture increased in strength at every age, and by 720 days had the highest strength. The steady increase for the 60% PC/25% S/15% FA mixture also holds for the field-cured cylinders (Figure 3.26b) and cores (Figure 3.26c), while the mixture with 65% PC/35% S exhibited a drop in strength between 360 and 720 days for both the field-cured cylinders and cores and the mixture with 100% PC exhibited a small gain between 360 and 720 days for the field-cured specimens and a drop over the same period for the cores. Comparing the 720-day with 28-day strengths, on average, the 100% PC mixtures had strengths less than 20 percent greater than the 28-day strengths; the mixtures with 65% PC/35% S had strengths 18 to 25 percent greater than 28-day strengths; and the 60% PC/25% S/15% FA mixtures had strengths that were 34 to 50 percent greater than the 28-day strengths.

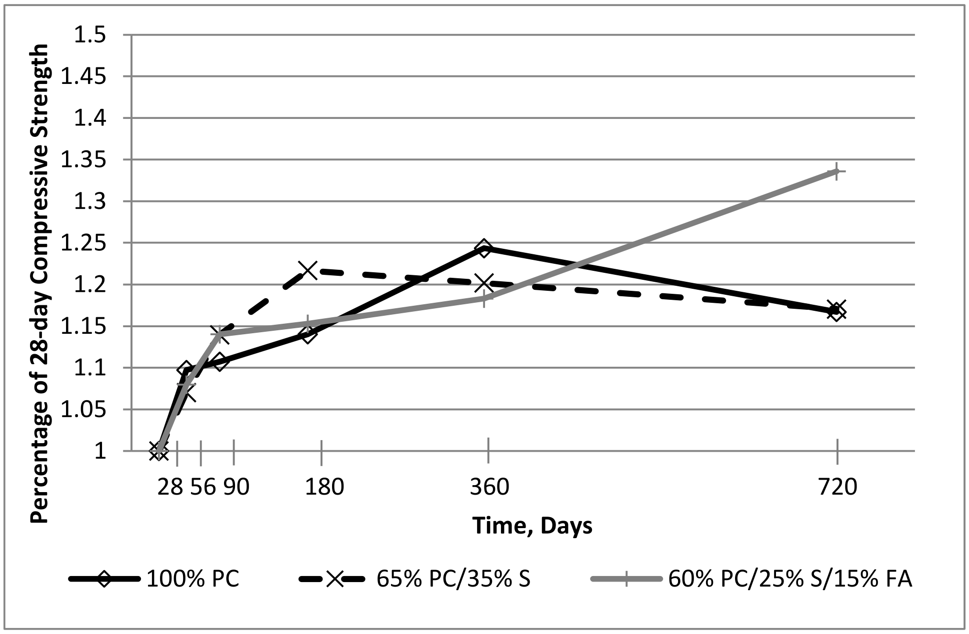

Figure 3.19a: Compressive strength relative to 28-day strength for lab-cured cylinders.

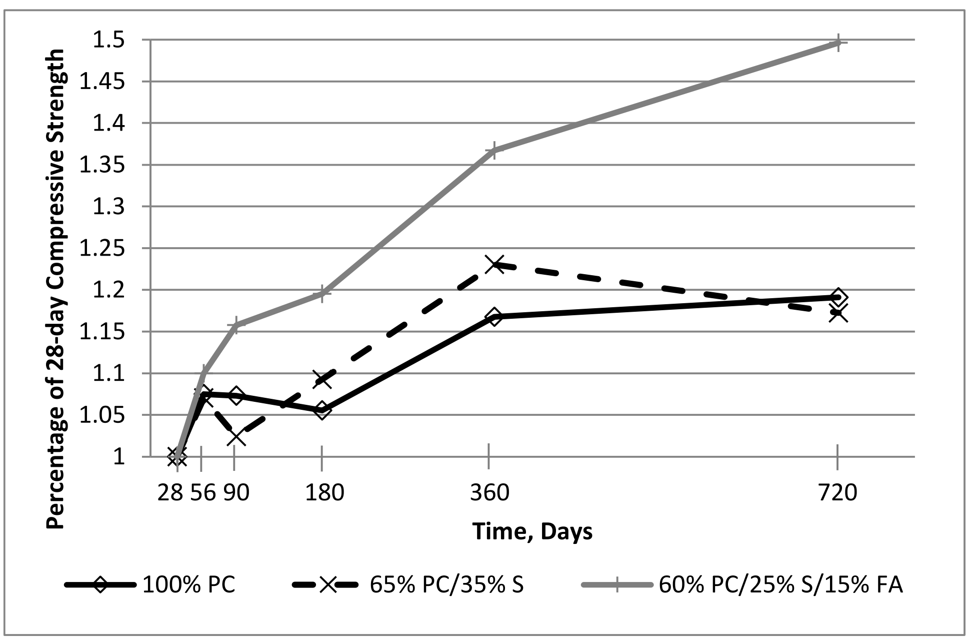

Figure 3.19b: Compressive strength relative to 28-day strength for field-cured cylinders.

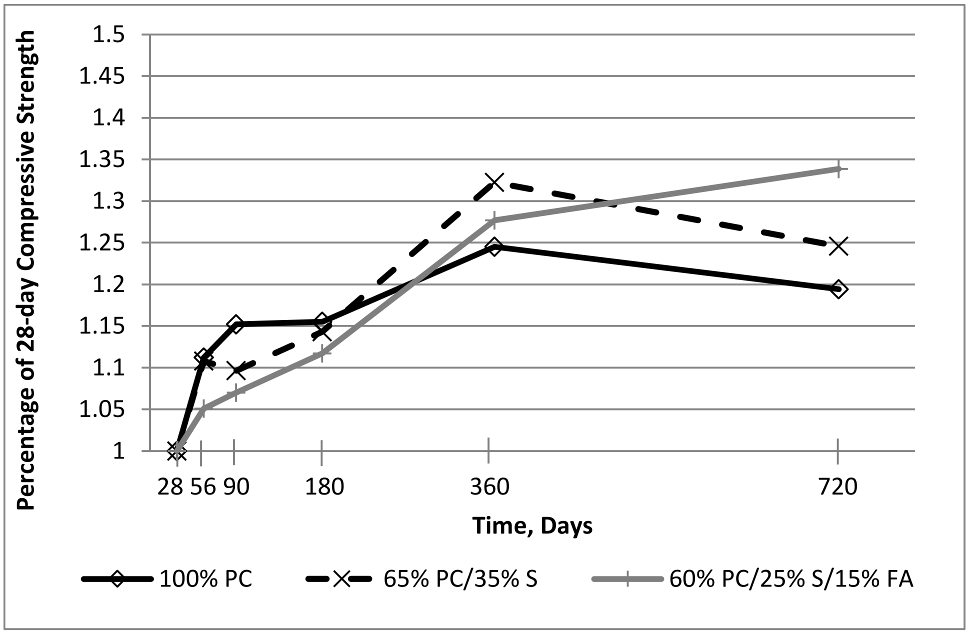

Figure 3.19c: Compressive strength relative to 28-day strength for cores.

3.2.4.4 Effect of Plastic Concrete Properties

Figure 3.20 shows the relationship between actual *w/cm* ratio and 28-day core strength. As expected, a clear downward trend is observed, with increasing *w/cm* ratio directly correlated to lower 28-day compressive strength. With the exception of the fall slab with 60% PC/25% S/15% FA, this effect is consistent across all seasons and all mixtures evaluated in this study. The low strength observed on the fall slab with 60% PC/25% S/15% FA can be attributed to the cold weather in the week following casting.

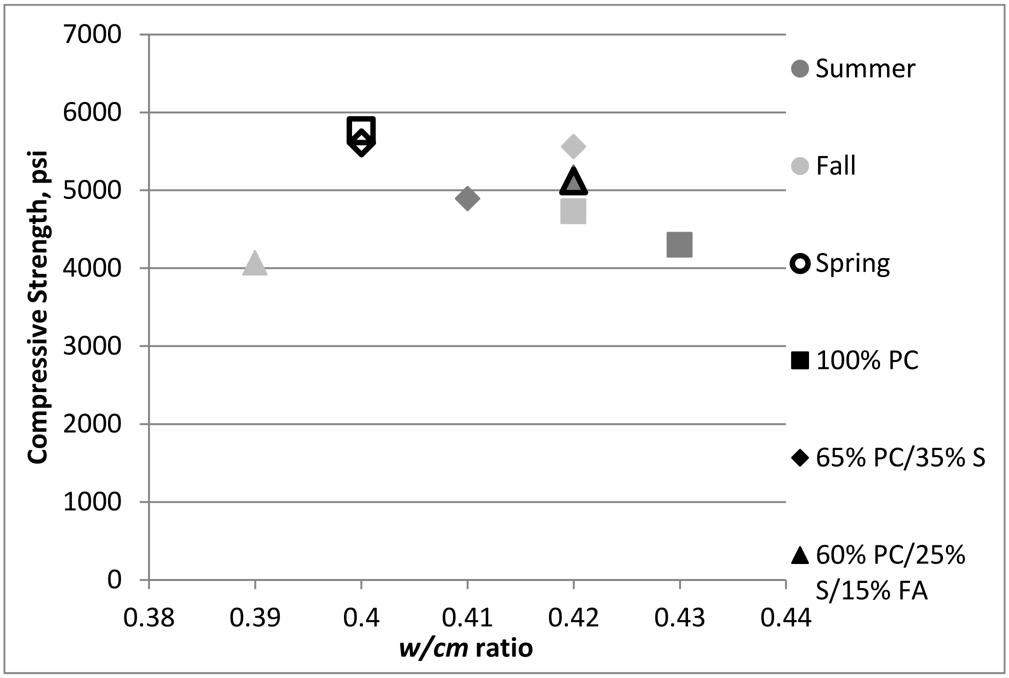

Figure 3.20: 28-day core strength vs. *w/cm* ratio.

Figure 3.21 shows the relationship between concrete temperature at the time of casting and the 28-day core strength. Excessively hot or cold concrete has an adverse effect on 28-day concrete strength, with the greatest concrete strength obtained for concrete cast near 70 °F. As discussed in Section 3.4.2.1, however, the longer-term strength of concrete cast in cold weather was comparable to that of concrete cast in moderate temperatures.

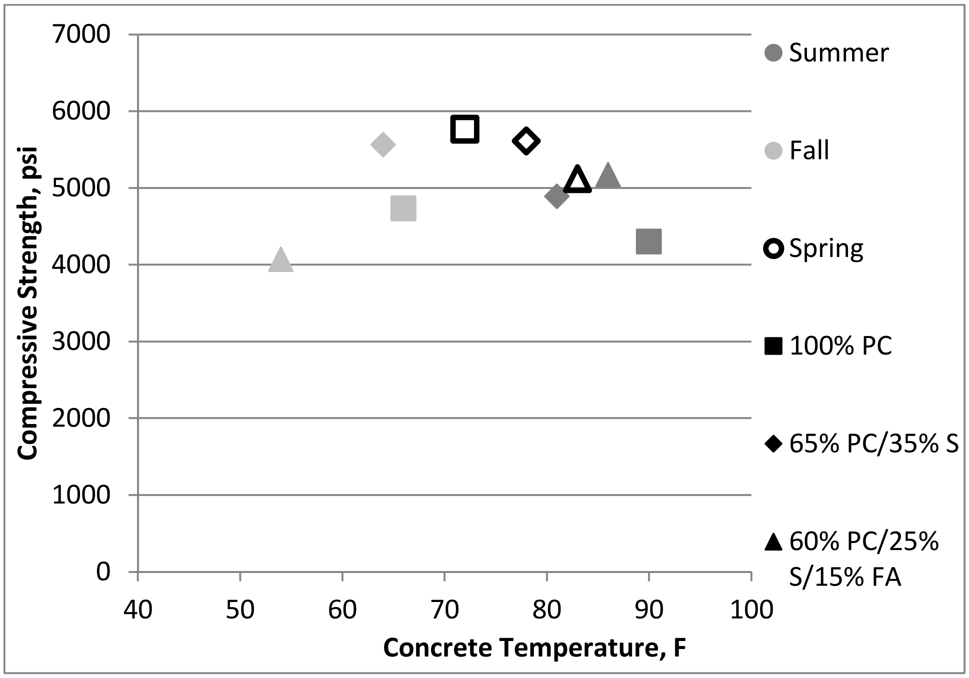

Figure 3.21: 28-day core strength vs. concrete temperature at casting.

Figure 3.22 shows the relationship between air content and 28-day core strength. Within a given season, there appears to be a downward trend, with increasing air content corresponding to reduced concrete strength. This effect is not persistent across seasons, however; the spring slab with 60% PC/25% S/15% FA, with the highest air content, had a 28-day core strength over 5000 psi, greater than many of the summer and fall slabs with lower air contents. These comparisons show that, as expected, increased air content can be related to reduced strength, but by itself is not an accurate predictor of compressive strength.

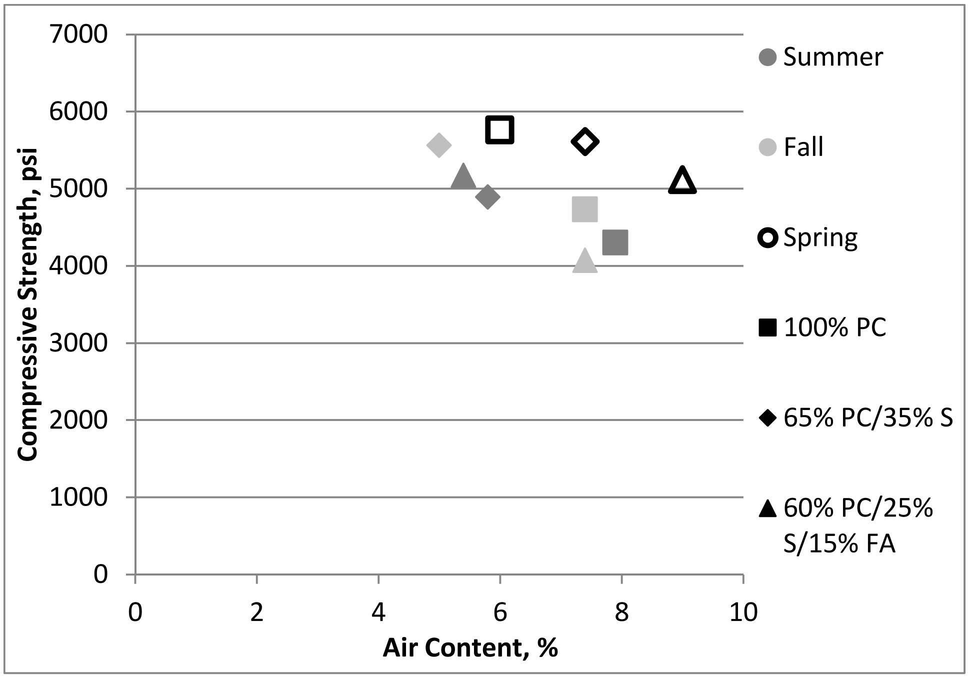

Figure 3.22: 28-day core strength vs. air content.

Figure 3.23a shows the relationship between unit weight and 28-day core strength. As expected, an increase in unit weight resulted in an increase in compressive strength. An increase in unit weight from 140 to 145 lb/ft^3 resulted in an almost 1500 psi increase in compressive strength (note that unit weight was not obtained for the summer slab with 60% PC/25% S/15% FA). The effect *is* consistent across seasons and mixtures evaluated in this study. This effect is likely not directly due to unit weight, but to other factors, principally air content and *w/cm* ratio (Figure 3.23b), that affect both strength and unit weight.

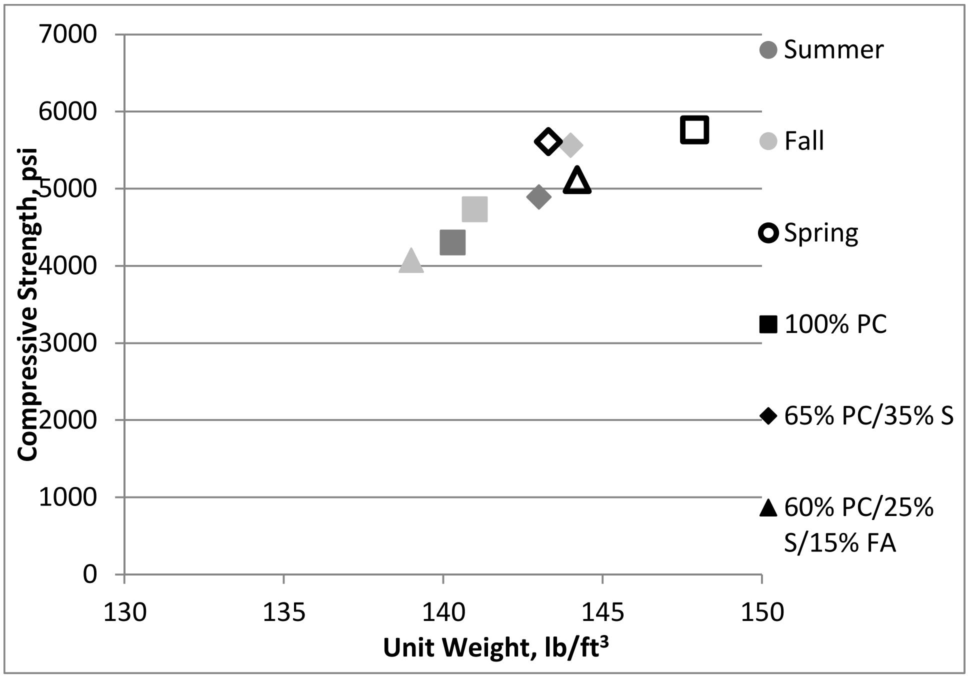

Figure 3.23a: 28-day core strength vs. unit weight.

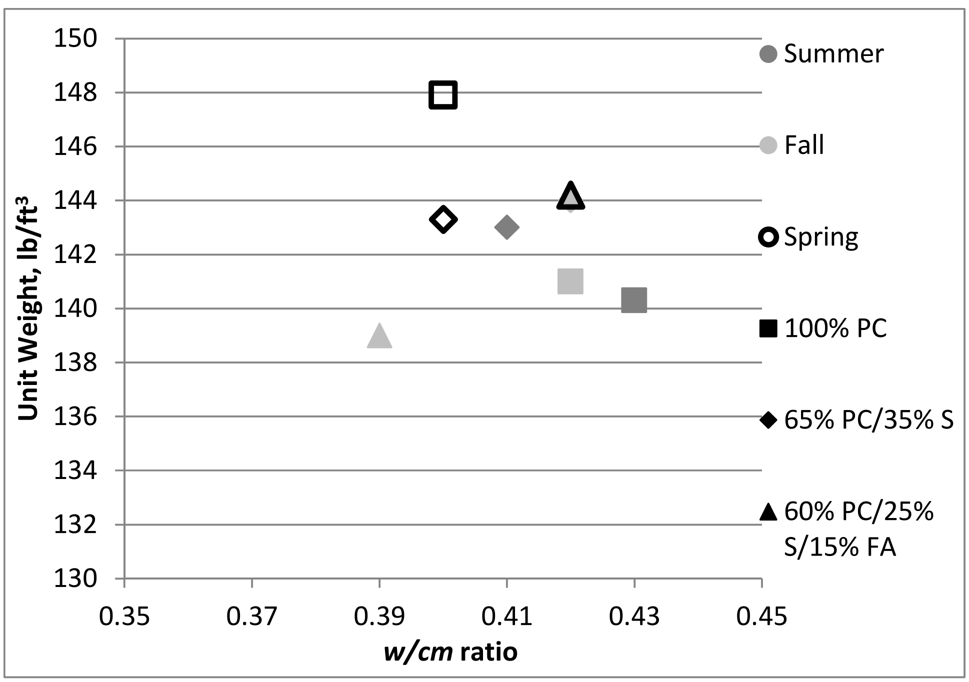

Figure 3.23b: Unit weight vs. *w/cm* ratio.

3.3 Boil Test Results

3.3.1 100% Portland Cement (PC) Mixtures

The boil test results for the 100% portland cement (PC) mixture cast in the summer are shown in Figure 3.324. The values represent the average volume of permeable pore space (percent voids) of three cylinders (or cores), with the range of values obtained given by error bars. KDOT has set an upper limit of 12.5% for lab-cured specimens tested at 28 days. This limit is not applicable for specimens at ages other than 28 days or for field-cured cylinders or cores; however, it will be used as a reference and is shown on Figure 3.24 and those that follow as a horizontal line. Consistent with the analysis of compressive strength, differences in boil test results between cylinder types or cores were considered statistically significant if a Student's t-test between two sets of data showed the probability that the differences were due to natural variation (chance) was less than 10 percent ($p < 0.1$). The results of Student's t-test for the boil test results are summarized in Tables B.7 through B.12 and B.29 in Appendix B. Individual specimen data are given in Appendix C.

For the summer slab with 100% PC, the lab-cured cylinders had the lowest average percent voids at all ages except 180 days, when the cores had the lowest value. The cores had percentages similar to, but slightly higher (less than 1 percentage point) than the lab-cured cylinders at most ages, although this difference was not statistically significant at ages less than 360 days. The field-cured cylinders had the highest percent voids, exceeding 13% at all ages. This difference was statistically significant at most ages (56, 90, 180, 360, and 720 days when comparing to lab-cured cylinders; 56, 90, and 180 days when comparing to cores). Variation between specimen types at a given age was as high as 2 percentage points. For the lab-cured cylinders, the percent voids tended to decrease with age. This trend was not observed on either field-cured cylinders or cores.

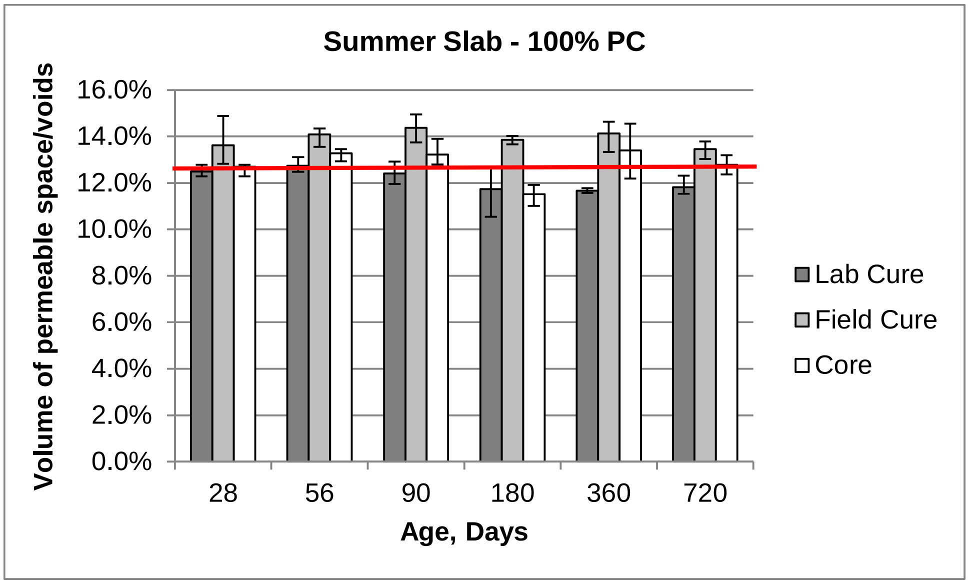

Figure 3.24: Boil test-percent voids for summer slab with 100% PC mixture.

The boil test results for the 100% PC mixture cast in the fall are shown in Figure 3.25. Fewer voids were present in the fall slab than the summer slab; the only samples to exceed 12.5% were the field-cured cylinders at 28 and 56 days and the cores at 28 and 720 days. The differences between 28-day boil test results, however, were not statistically significant ($p > 0.5$). The lab-cured cylinders had the lowest average percent voids at all ages. The cores had percentages similar to (less than 1 percentage point difference) the lab-cured cylinders at all ages, except at 720 days ($p = 0.007$), and the field-cured cylinders had the highest percent voids at all ages, except at 180 and 720 days. For both the cylinders and cores, the percent voids tended to decrease with age, although the percent of voids increased at 720 days for the cores.

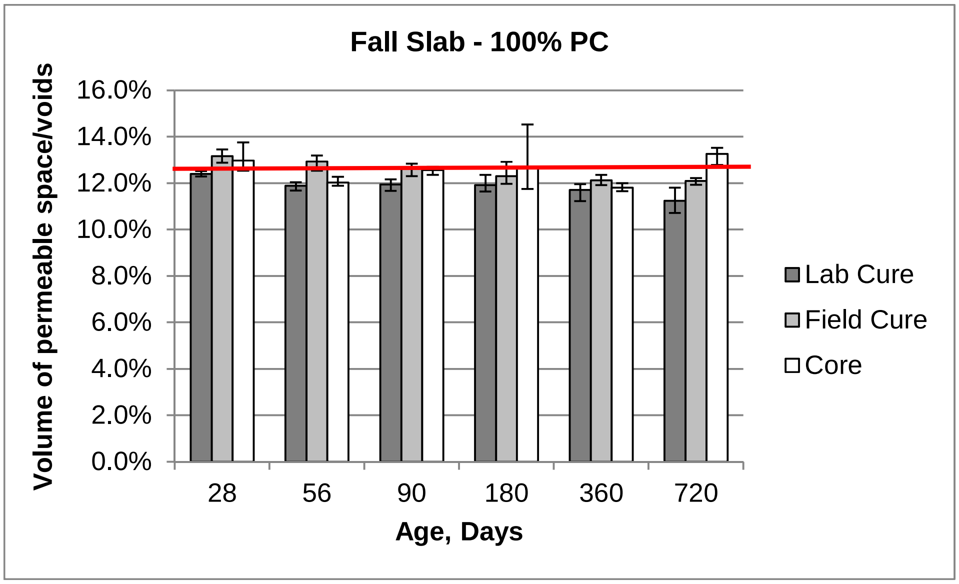

Figure 3.25: Boil test-percent voids for fall slab with 100% PC mixture.

The boil test results for the 100% PC mixture cast in the spring are shown in Figure 3.26. The spring slab had the lowest percent voids of the 100% portland cement (PC) slabs, with all averages remaining below 12.5% at all ages for all specimen types. A comparison of cylinders and cores from all three 100% portland cement (PC) slabs found this difference to be statistically significant ($p < 0.082$). The lab-cured cylinders had the lowest average percent voids at all ages. The cores had percentages similar to (less than 0.5 percentage points difference, $p > 0.21$) the lab-cured cylinders, and field-cured cylinders had the highest percent voids. There was much less variation in the values than for the summer slab; except for the values at 360 days, there was less than 1 percentage point difference between specimen types at all ages. Although there was some fluctuation in values for both cylinders and cores, the percent of voids tended to decrease with age.

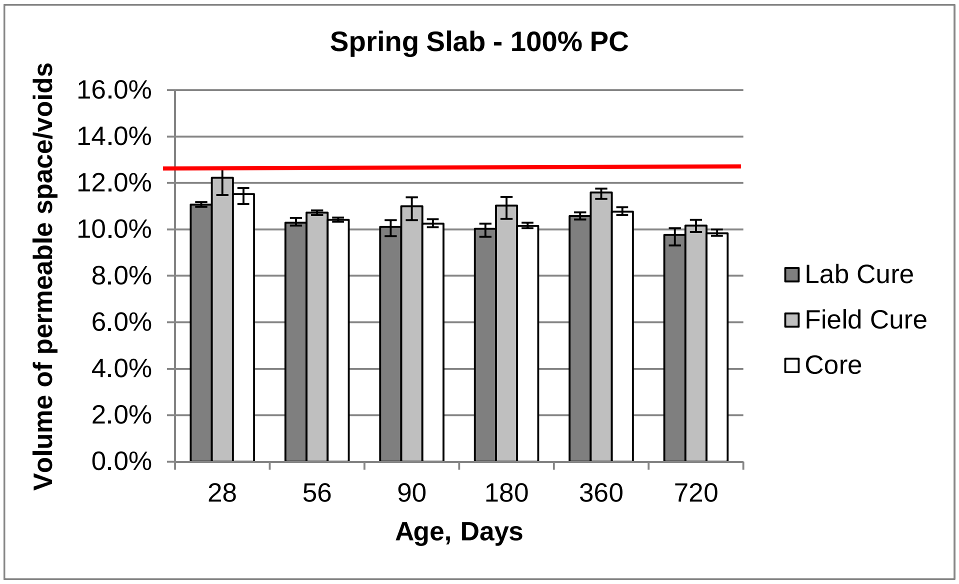

Figure 3.26: Boil test-percent voids for spring slab with 100% PC mixture.

3.3.2 65% Portland Cement/35% Slag Mixtures

The boil test results for the 65% portland cement/35% slag mixture cast in the summer are shown in Figure 3.327. Fewer voids were present in this slab than the 100% PC summer slab, although at 28 and 56 days, this difference was not statistically significant ($p > 0.17$) for cylinders or cores. The lab-cured cylinders remained below 12.5% at all ages. The field-cured cylinders and cores both exceeded 12.5% at 28, 56, and 90 days; by 720 days, all samples had voids below 12%. By comparison, the field-cured cylinders and cores for the summer slab with 100% PC were over 13% at 720 days.

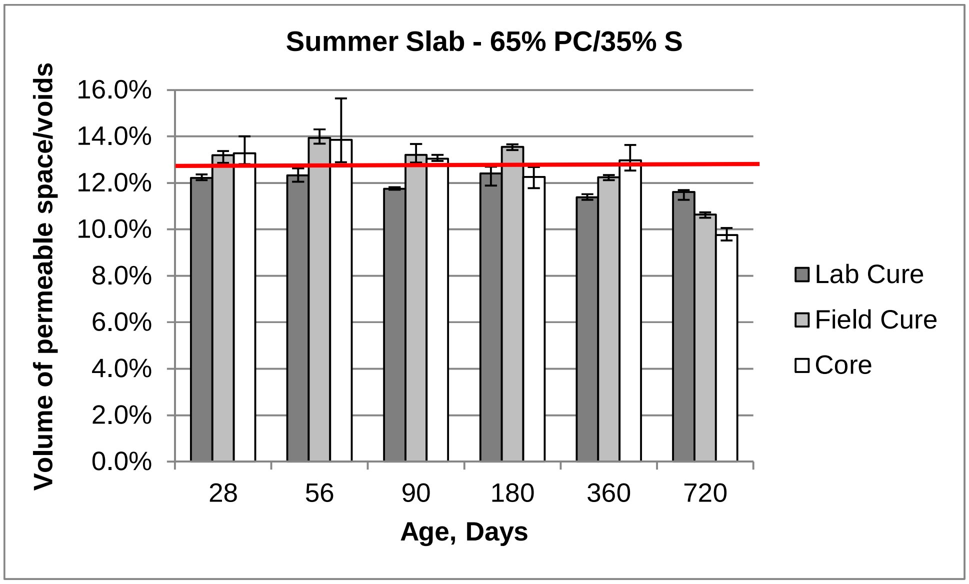

Figure 3.27: Boil test-percent voids for summer slab with 65% PC/35% S mixture.

The boil test results for the 65% PC/35% S mixture cast in the fall are shown in Figure 3.28. The voids present in this slab are comparable to those in the 100% PC slab cast in the fall, with both slabs having core and cylinder void contents between 12% and 13% at 56 days. The voids in the concrete for this slab were slightly lower than for the summer slab with the same mixture, which had voids as high as 14% at 56 days. An analysis of 28-day boil test results found that the difference between the summer and fall slabs for this mixture to be statistically significant for lab-cured cylinders (p = 0.057) and cores (p = 0.060), but not for field-cured cylinders (p = 0.56). The void content of the lab-cured cylinders remained below 12% at all ages. The void content of the field-cured cylinders exceeded 12.5% at 28, 56, 90, and 180 days; the void content of the cores exceeded 12.5% at 56 and 180 days.

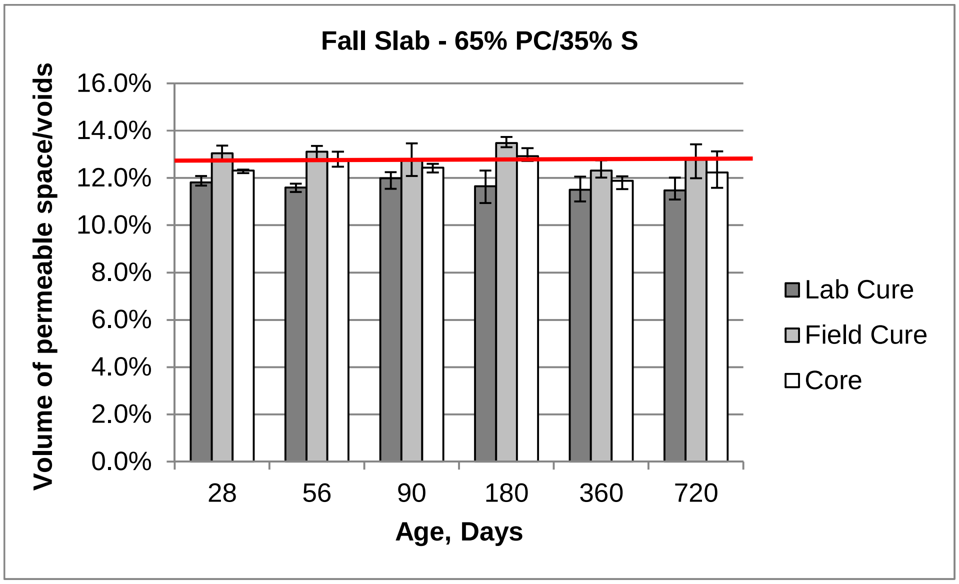

Figure 3.28: Boil test-percent voids for fall slab with 65% PC/35% S mixture.

The boil test results for the 65% PC/35% S mixture cast in the spring are shown in Figure 3.29. The voids present in this slab are comparable to those of the fall slab with 65% PC/35% S, with both having voids at 56 days ranging from just below 12% to around 13%. The void content of the lab-cured cylinders remained below 12% at all ages. The void contents of the field-cured cylinders were below 12.5% only at 720 days, while the void contents of the cores were generally below those for the field-cured cylinders (except at 90 and 720 days) and below 12.5% at 180 and 720 days.

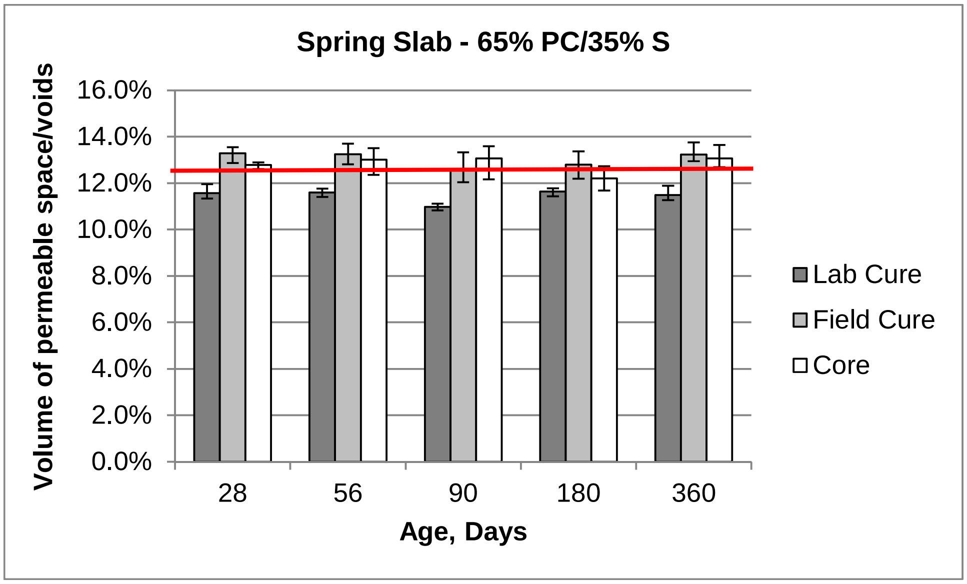

Figure 3.29: Boil test-percent voids for spring slab with 65% PC/35% S mixture.

3.3.3 60% PC/25% S/15% FA Mixtures

The boil test results for the 60% PC/25% S/15% FA mixture cast in the summer are shown in Figure 3.30. The void content of this slab was significantly higher than any of the 100% PC or 65% PC/35% S mixtures; only the cores tested at 180 days had a void content below 12.5%. The field-cured cylinders had the highest percentage of voids at all ages, except at 720 days.

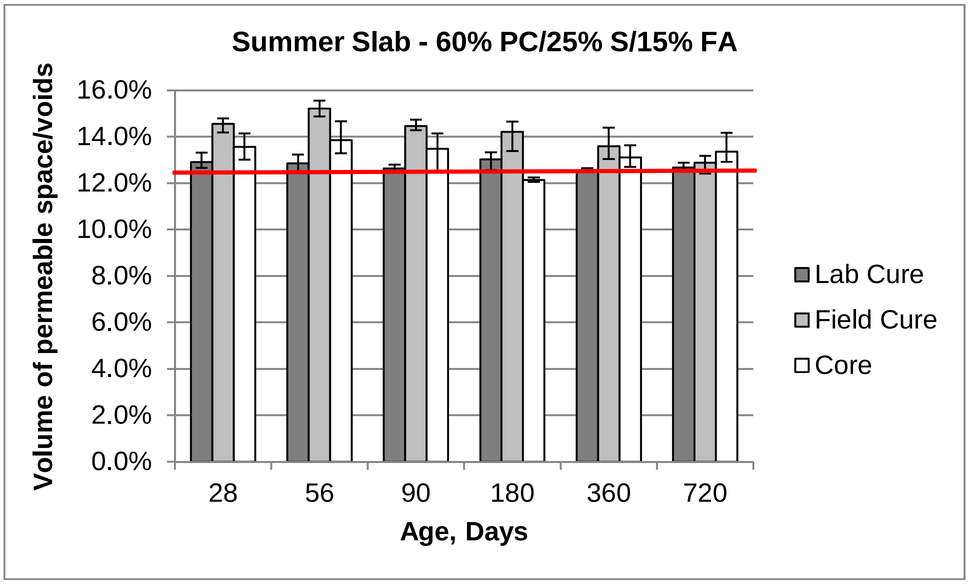

Figure 3.30: Boil test-percent voids for summer slab with 60% PC/25% S/15% FA mixture

The boil test results for the 60% PC/25% S/15% FA mixture cast in the fall are shown in Figure 3.31. The percentage of voids present in this slab was the highest of any of the slabs; no readings were below the 12.5% limit. A comparison at 28 days found this difference to be statistically significant when comparing against all other slabs with lab-cured cylinders ($p < 0.00037$), field-cured cylinders ($p < 0.0076$), and cores ($p < 0.018$).

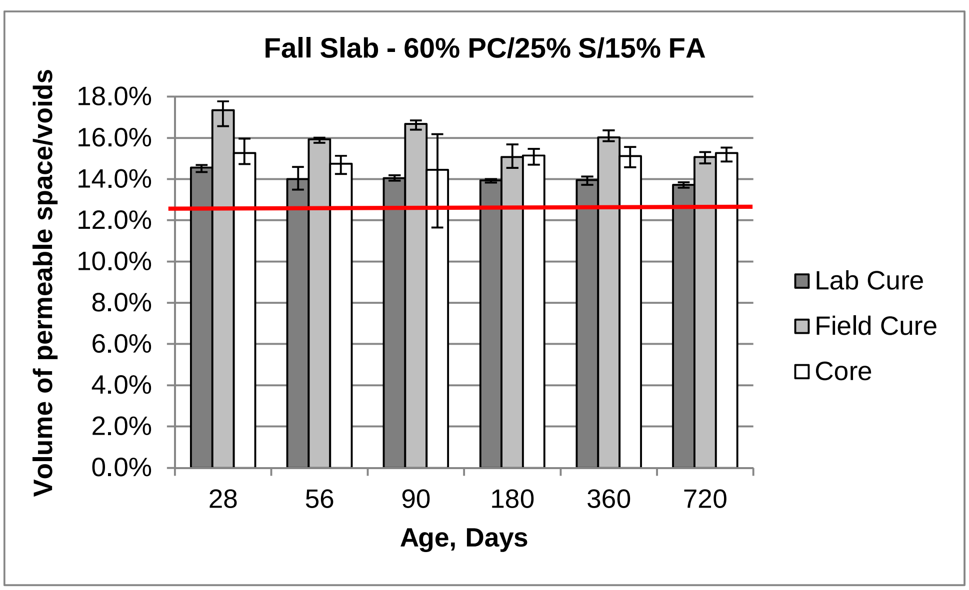

Figure 3.31: Boil test-percent voids for fall slab with 60% PC/25% S/15% FA mixture.

The boil test results for the 60% PC/25% S/15% FA mixture cast in the spring are shown in Figure 3.32. The percentage of voids present in this slab are lower than the other slabs cast for this mixture ($p < 0.0097$) – unlike the slabs cast in the summer and fall, no sample had a percentage of voids greater than 14%. As with the other slabs, the field-cured cylinders tended to have the highest percentage of voids at a given age, whereas the lab-cured cylinders had the lowest percentage of voids.

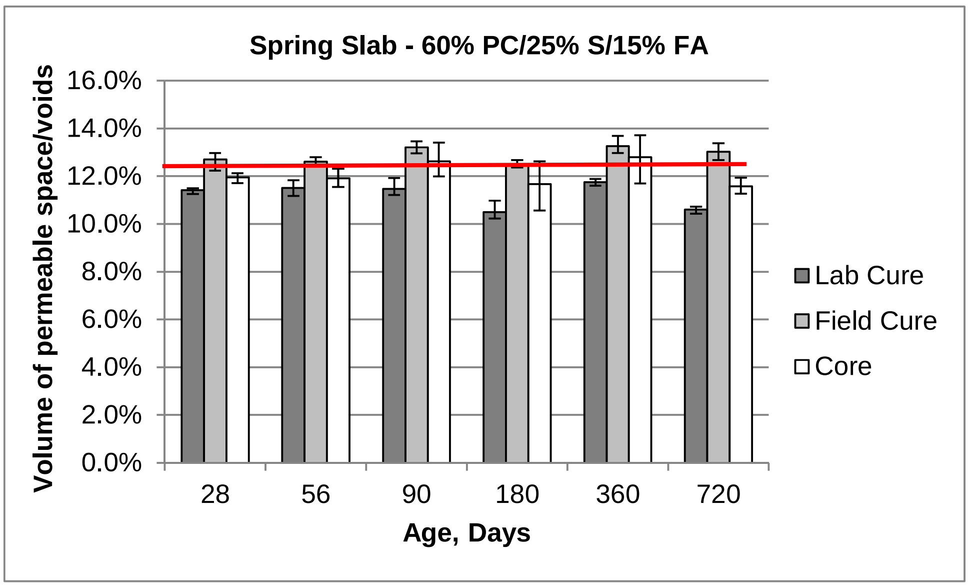

Figure 3.32: Boil test-percent voids for spring slab with 60%PC/25% S/15% FA mixture.

3.3.4 Effect of Plastic Concrete Properties

Figure 3.33 shows the relationship between the actual *w/cm* ratio and the 28-day void content of cores. The fall slab with the 60% PC/25% S/15% FA mixture, with the lowest actual *w/cm* ratio, had the highest percentage of voids, although this is likely coincidental. Nonetheless, no significant trend was noted between percentage of voids and *w/cm* ratio.

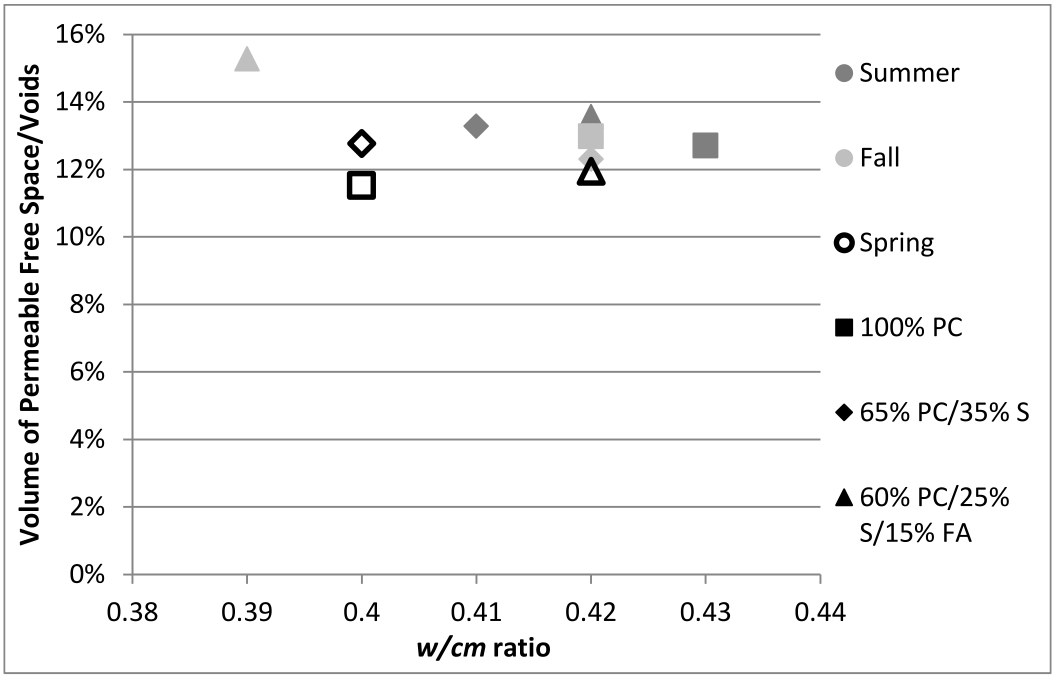

Figure 3.33: Percentage of voids at 28 days for cores vs. *w/cm* ratio.

Figure 3.34 shows the relationship between the concrete temperature at the time of casting and voids in 28-day cores. No clear trend is observed, although the lowest percentage voids was observed for concrete cast near 70 °F (spring slab with 100% portland cement) with warmer or colder concrete exhibiting higher void contents.

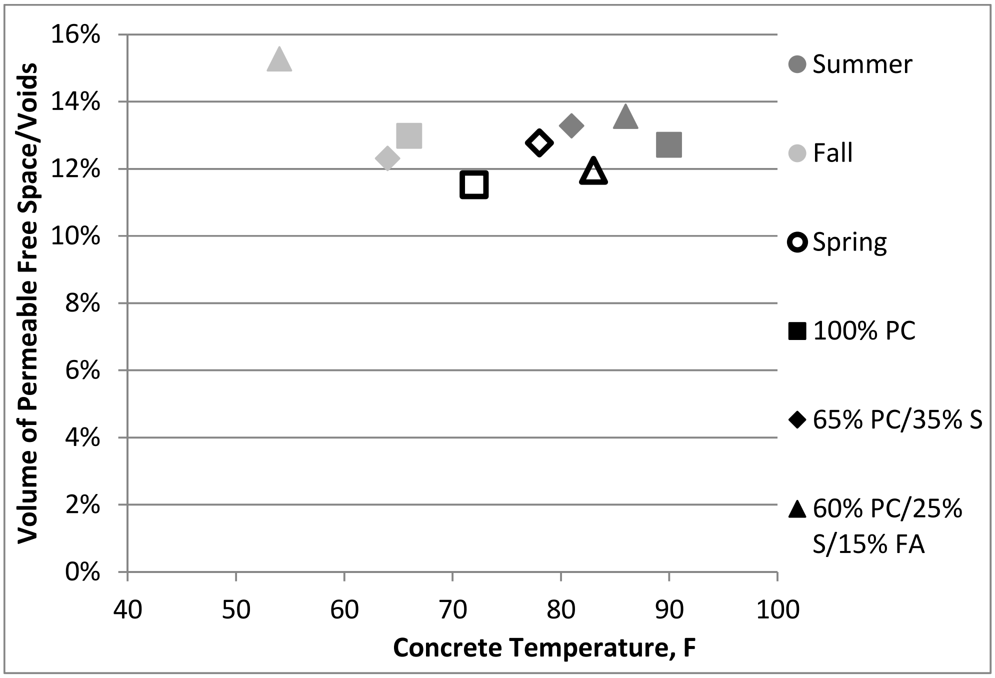

Figure 3.34: Percentage of voids at 28 days for cores vs. concrete temperature at casting.

Figure 3.35 shows the relationship between the air content and the void content of the cores at 28 days. Curiously, no trend is observed, even when controlling for season or mixture. This could be due to variation between the plastic and hardened air contents of the concrete – research by Hover and Phares (1996) found the air content of hardened concrete could differ greatly from the air content measured in plastic concrete. Hardened air contents were not measured in this study.

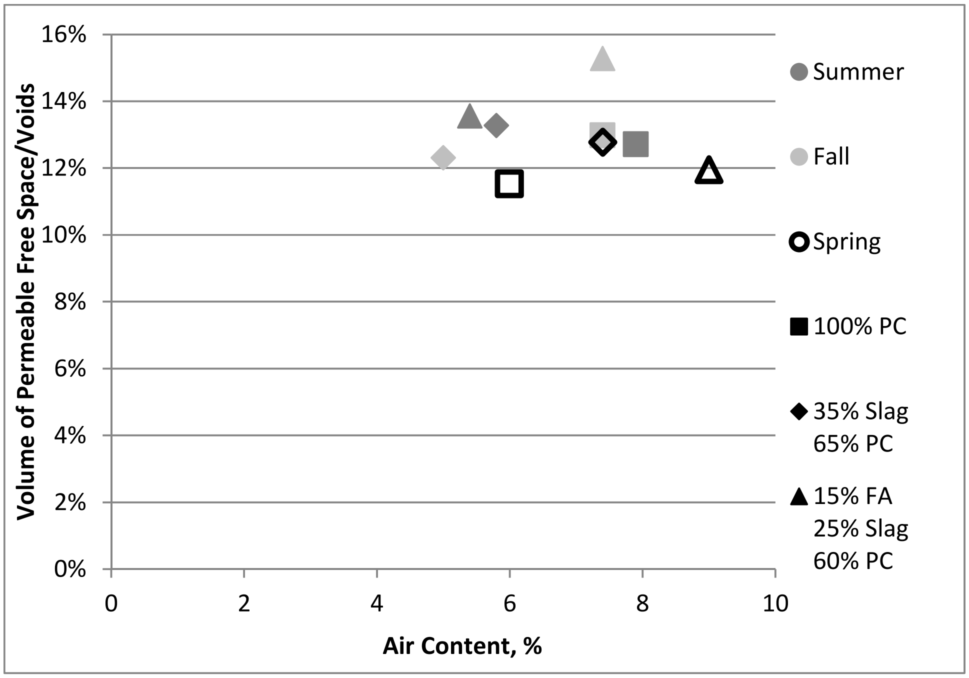

Figure 3.35: Percentage of voids at 28 days for cores vs. concrete air content.

Figure 3.36a shows the relationship between the unit weight and the 28-day void content of the cores. (Unit weight was not measured for the summer slab with 60% PC/25% S/15% FA.) In general, as the unit weight increased, the percentage of voids decreased; as the unit weight increased from 138 to 148 lb/ft^3, the percentage of voids decreased from roughly from 14% to 10%. This effect was generally persistent across all mixtures and seasons. To verify this, the unit weight is also compared to the void content of lab-cured cylinders. As shown in Figure 3.36b, the same general trends are seen as for the comparison between unit weight and core boil test results (Figure 3.36a), but with somewhat less scatter for the lab-cured cylinders than for the cores. This decrease in permeable free space also likely contributes to the increase in compressive strength with unit weight (Figure 3.23a).

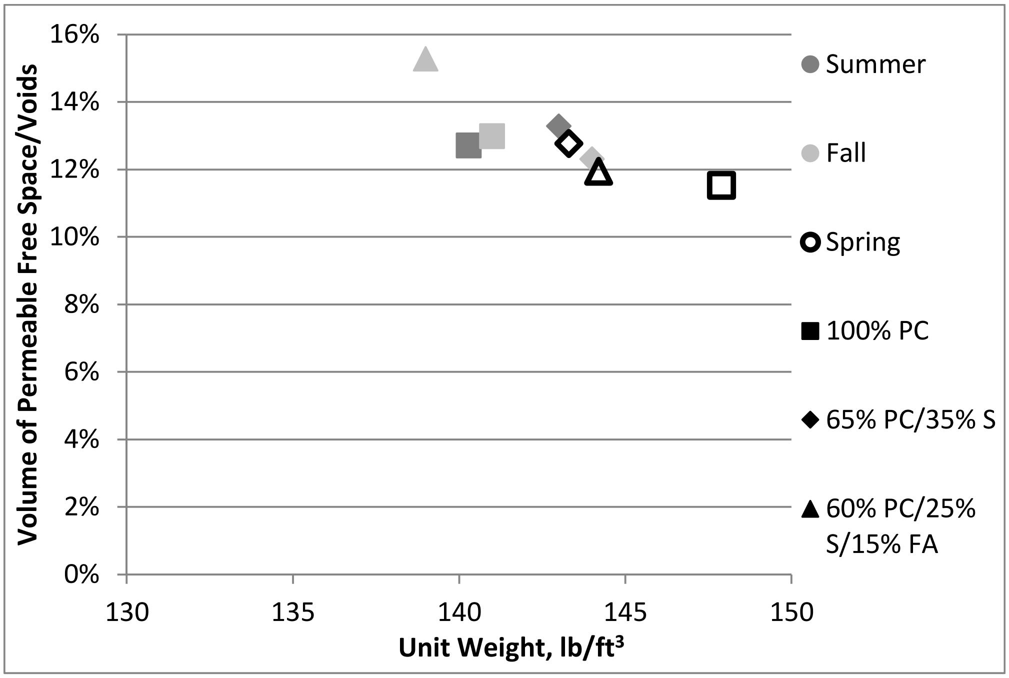

Figure 3. 36a: Percentage of voids at 28 days for cores vs. unit weight.

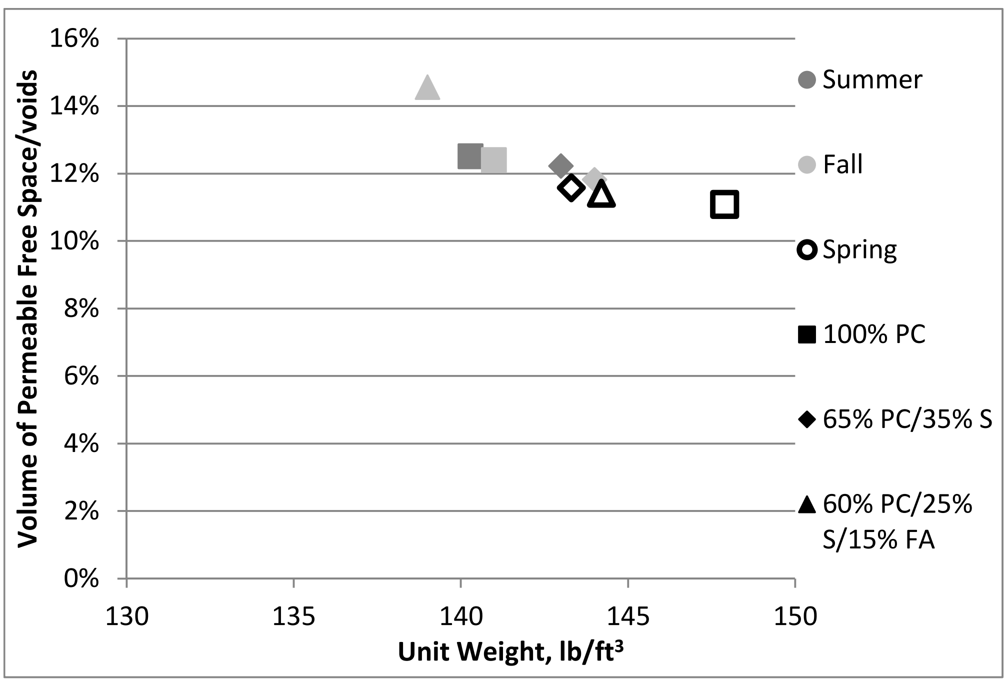

Figure 3.36b: Percentage of voids at 28 days for lab-cured cylinders vs. unit weight.

3.3.5 Comparison between Cylinders and Cores

Figure 3.37a shows the ratio of average percent voids from field-cured cylinders to average percent voids from lab-cured cylinders for all slabs at all ages. A ratio less than 1.0 indicates that the percent voids in the slab as measured by field-cured cylinders was less than that obtained from lab-cured cylinders. As shown in Figure 3.37a, the percentage of voids in field-cured cylinders were almost always (98% of all data points) greater than that found in lab-cured cylinders – only the summer slab with 65% PC/35% S at 720 days had field-cured cylinders with a lower percentage of voids than lab-cured cylinders. The average ratio of voids in field cylinders to lab-cured cylinders was 1.11.

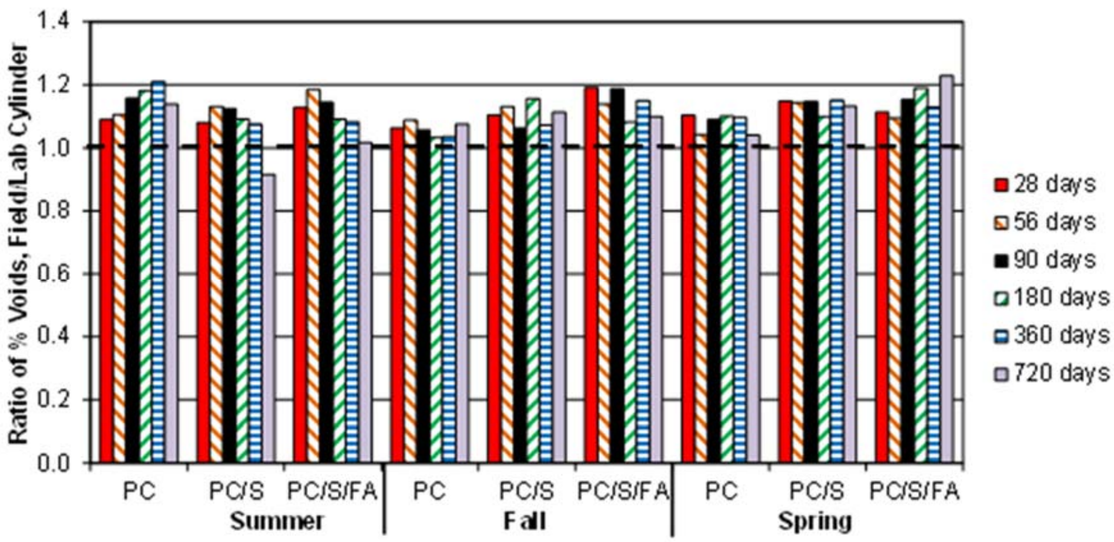

Figure 3.37a: Ratio of percent voids in field-cured cylinders to percent voids in lab-cured cylinders.

Figure 3.37b shows the ratio of average percent voids from cores to average percent voids from lab-cured cylinders for all slabs at all ages. As shown in Figure 3.37b, the percentage of voids in cores were frequently (93% of all data points) greater than that found in lab-cured cylinders. The only samples to return a percentage voids from cores less than that found in lab-cured cylinders were from slabs cast during the summer, 100% PC at 180 days, 65% PC/35% S at 180 and 720 days, and 60% PC/25% S/15% FA at 180 days. The average ratio of voids in cores to lab-cured cylinders was 1.063.

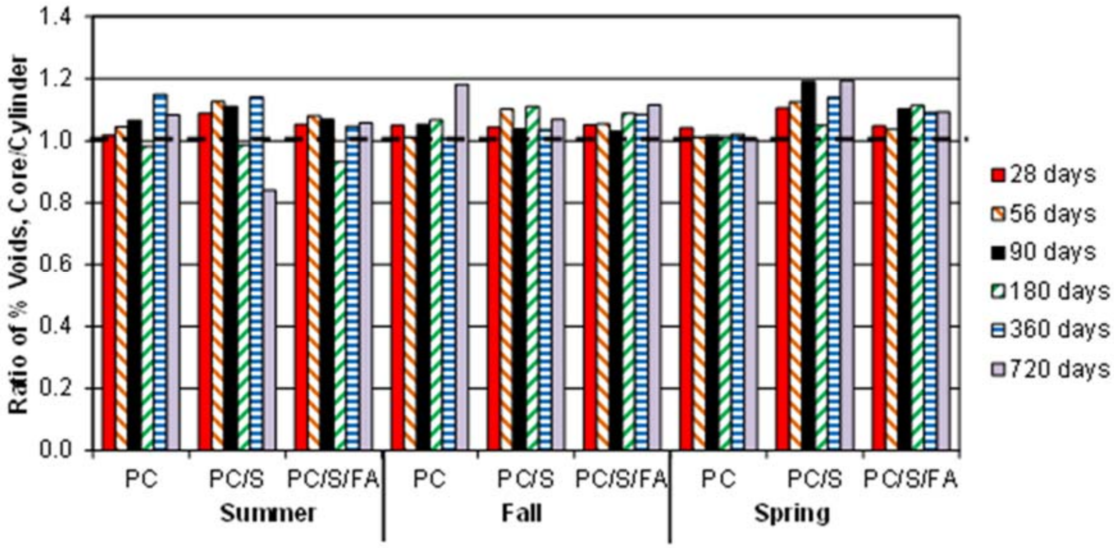

Figure 3.37b: Ratio of percent voids in cores to percent voids in lab-cured cylinders.

Figure 3.37c shows the ratio of average percent voids from cores to average percent voids from field-cured cylinders for all slabs at all ages. Unlike the comparison with lab-cured cylinders, the percentage of voids in cores was frequently (83% of all data points) less than for field-cured cylinders. This effect was persistent across all temperature ranges. Most of the cases where cores had a greater percentage of voids than the field-cured cylinders were from samples tested at 360 or 720 days; however, a clear trend in this regard is lacking. The average ratio of voids in cores to field-cured cylinders was 0.958.

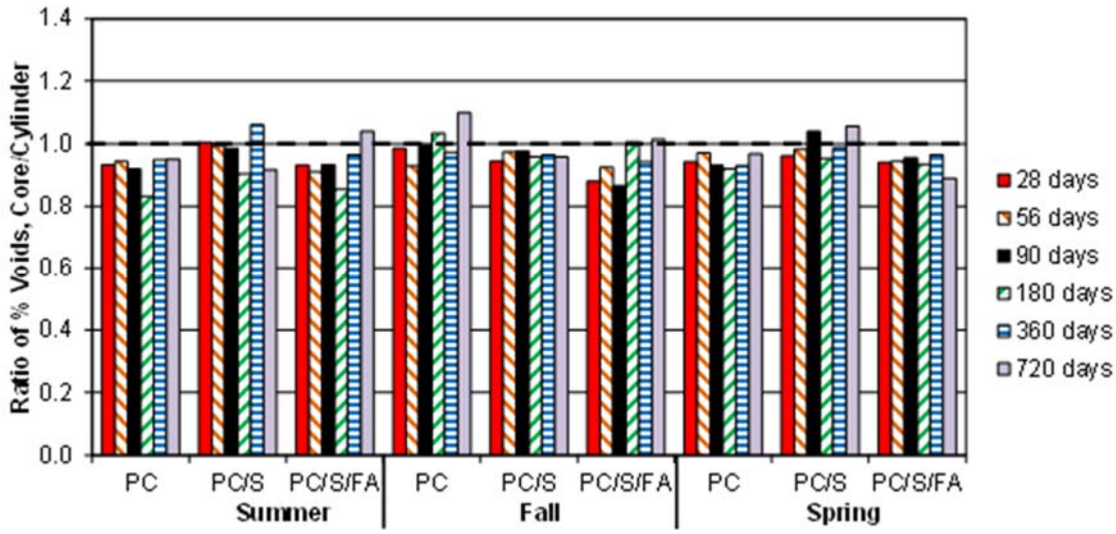

Figure 3.37c: Ratio of percent voids in cores to percent voids in field-cured cylinders.

As described in Section 3.3.3, lab-cured cylinders exhibited fewer voids than either field-cured cylinders or cores in nearly all cases, and field-cured cylinders tended to have the greatest percentage of voids

Table 3.2 summarizes the Student's t-test comparisons shown in Tables B.7 through B.12 in Appendix B. As shown in Table 3.2, only 1.9% of lab-cured cylinders had a greater percentage of voids than the matching field-cured cylinders with differences in void content that were statistically significant compared to 87% of field-cured cylinders with a higher void content than the lab-cured cylinders. In 11.1% of the cases, the differences were not statistically significant. The only difference in these specimens was the curing regime. When comparing lab-cured specimens and cores, 3.7% of lab-cured cylinders had a greater percentage of voids than the matching cores with differences in void content that were statistically significant compared to 40.7% of the cores with a higher void content than the lab-cured cylinders. In 55.6% of the cases, the differences were not statistically significant. Lab-cured cylinders and cores differ in both degree of consolidation and curing regime. Comparing the field-cured cylinders and cores, those with statistically significant differences included 38.9% of field-cured cylinders with more voids than the cores and 1.9% of cores with more voids than field-cured cylinders. In 57.4% of the cases, the differences were not statistically significant.

Table 3.2: Percentage of Specimens with Statistically Significant Boil Test Differences

Comparison	Percentage of Specimens
Lab vs. Field	
Lab-cured cylinder more voids	1.9%
Field-cured cylinder more voids	87.0%
Difference not statistically significant	11.1%
Lab vs. Core	
Lab-cured cylinder more voids	3.7%
Core more voids	40.7%
Difference not statistically significant	55.6%
Field vs. Core	
Field-cured cylinder more voids	38.9%
Core more voids	1.9%
Difference not statistically significant	57.4%

For the 100% PC mixtures, the high heat of summer appeared to adversely affect the permeability of concrete. The summer slab (Figure 3.24) exhibited a much greater percentage of voids than either the fall or spring slabs (Figures 3.25 and 3.26). This effect was not present in the mixtures with SCMs. It is likely the slower hydration and lower peak temperature of mixtures with SCMs resulted in less moisture loss in hot weather, allowing for more complete hydration and fewer voids. For slabs cast in the fall and spring (where temperatures were cooler and moisture loss was not as rapid), mixtures with SCMs did not have significantly fewer voids than the 100% portland cement (PC) mixtures. The fall slab with the 60% PC/25% S/15% FA mixture had the highest percentage voids of any slab, likely a result of the slow hydration process due to the cold weather.

3.4 RCP Test Results

This section presents the RCP test results for the mixtures. The plots show the average charge passed for three cylinders (or cores), with the range of values obtained given by error bars. Differences in charge passed between cylinder types or cores were considered statistically significant if a Student's t-test between two sets of data showed the probability that the differences were due to natural variation (chance) was less than 10 percent ($p < 0.1$). The results of Student's t-test are summarized in Tables B.13 through B.18 and B.30 in Appendix B. Individual specimen data are given in Appendix C. In the vast majority of the cases, the lab-cured cylinders exhibit the lowest charge passed, followed in turn by the cores, and the field-cured cylinders.

3.4.1 100% Portland Cement (PC) Mixtures

The rapid chloride permeability test results for the 100% portland cement (PC) mixture cast in the summer are shown in Figure 3.38. This and the following plots represent the average charge passed for three cylinders (or cores), with the range of values obtained shown by error bars. KDOT has set a limit of 3500 coulombs for lab-cured specimens tested at 56 days. This limit is not applicable for specimens at ages other than 56 days or for field-cured cylinders or cores; however, it is used as a reference and is shown on the plots as a horizontal line.

The lab-cured cylinders had the lowest average charge passed at all ages, never exceeding 3000 coulombs. The field-cured cylinders consistently had higher coulomb readings than the lab-cured cylinders with differences that were statistically significant ($p < 0.082$), exceeding 4000 coulombs at 28, 56, 90, and 180 days. The cores also consistently had higher coulomb readings than the lab-cured cylinders with differences that were statistically significant ($p < 0.073$) and exceeded 3500 coulombs at 28, 180, 360, and 720 days. The charge passed, as measured for both the lab-cured and field-cured cylinders, tended to decrease with time; however, this trend was not observed for the cores for which the charge passed remained constant or increased over time.

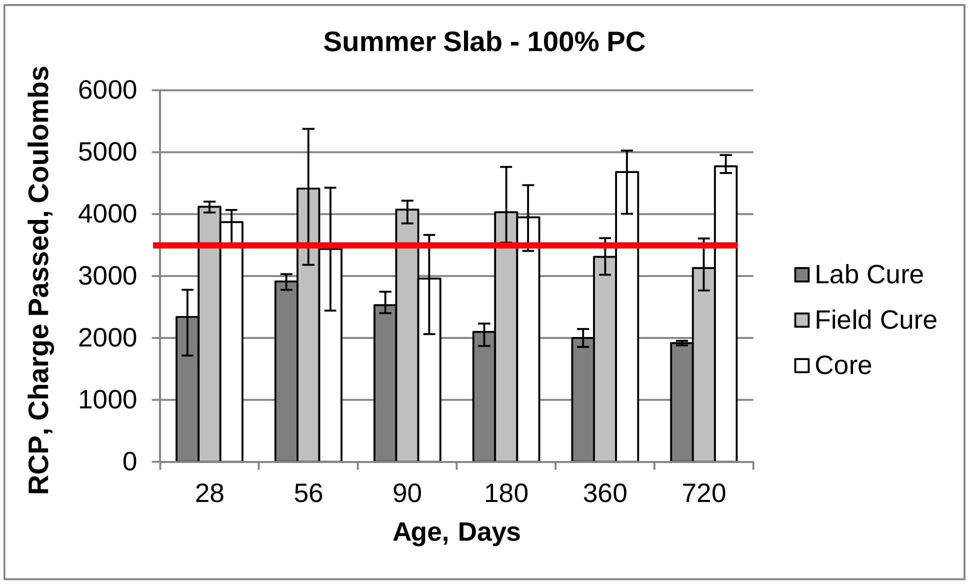

Figure 3.38: RCP test-charge passed for summer slab with 100% PC mixture.

The rapid chloride permeability test results for the 100% PC mixture cast in the fall are shown in Figure 3.39. The lab-cured cylinders had lower average coulomb readings than either field-cured cylinders ($p < 0.012$) or cores ($p < 0.047$) at all ages, only exceeding 3500 coulombs at 28 days. Unlike the summer slab with 100% PC, the charge passed for the fall slab with 100% PC decreased with age for all specimen types. After 180 days, the charge passed, as measured using both cylinders and cores, was below 3000 coulombs.

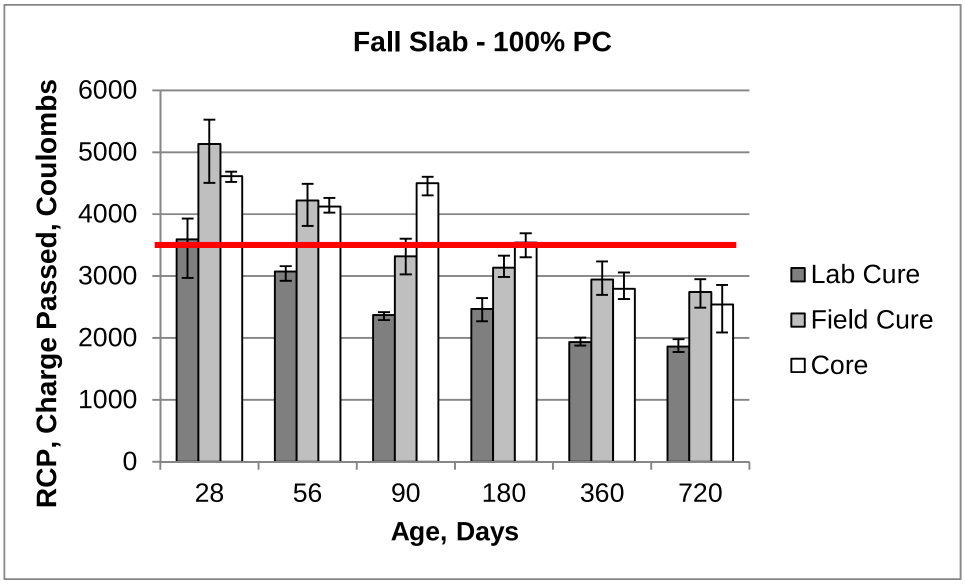

Figure 3.39: RCP test-charge passed for fall slab with 100% PC mixture.

The rapid chloride permeability test results for the 100% PC mixture cast in the spring are shown in Figure 3.40. Of the three slabs cast with portland cement, the spring slab had the lowest charge passed – only the field-cured cylinders at 28 days exceeded 3000 coulombs. At all ages, the lab-cured cylinders and cores had less than a 15% difference between average charge passed coulomb, differences that are not statistically significant ($p > 0.13$). The field-cured cylinders had greater coulomb, readings that were often 30% greater than the lab-cured cylinders ($p < 0.07$ except at 28 days) and cores ($p < 0.038$ except at 720 days). The charge passed for all specimens generally decreased with age.

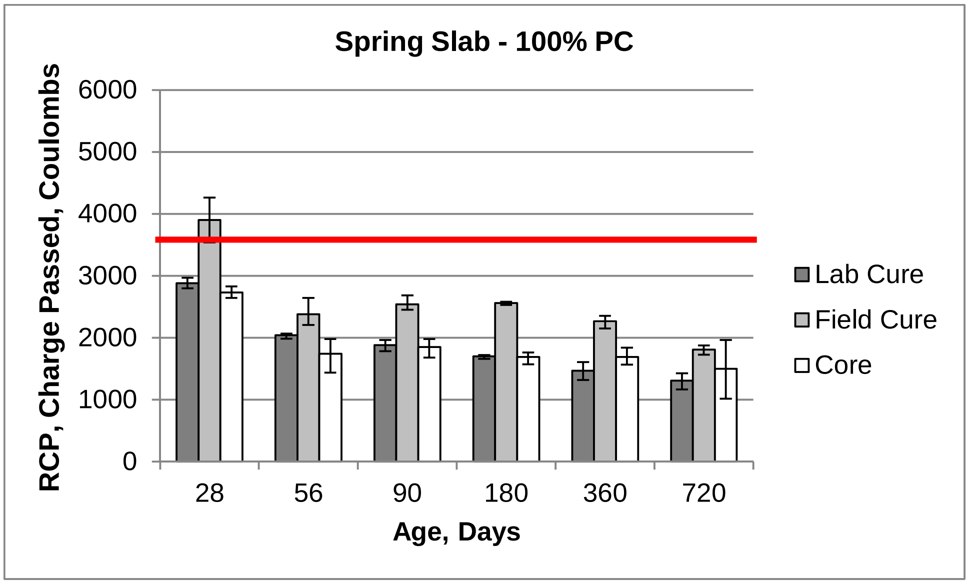

Figure 3.40: RCP test-charge passed for spring slab with 100% PC mixture.

3.4.2 65% Portland Cement/35% Slag Mixtures

The rapid chloride permeability test results for the 65% PC/35% S mixture cast in the summer are shown in Figure 3.41. The addition of slag resulted in lower coulomb readings than observed in the summer slab with 100% PC (p < 0.046); the average charge passed was below 3000 coulombs for all specimens at all ages. This is expected, as mixtures containing slag have smaller pores and lower ionic conductivity than 100% PC mixtures – a lower conductivity that is not directly associated with the penetration of chloride ions (ACI 226.1R-87, Wee, Suryavanshi, and Tin 2000). Lab-cured cylinders and cores had similar coulomb readings at all ages except 90 days and 720 days when the cores exhibited much greater charge passed. The field-cured cylinders consistently had 41% to 102% greater at all ages except 180 days when the value was 5%. The charge passed decreased with age for all specimens, with the exception of cores at 90 and 720 days.

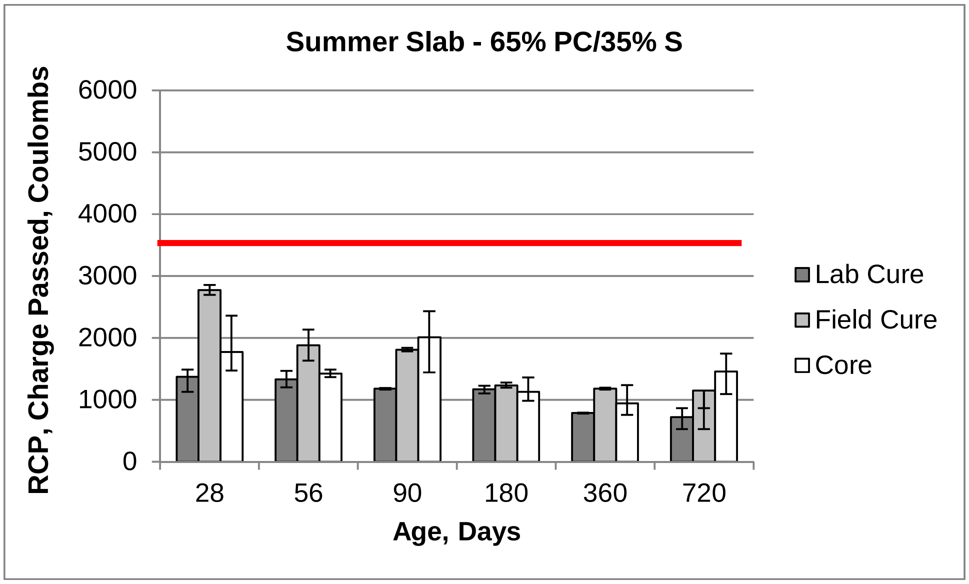

Figure 3.41: RCP test-charge passed for summer slab with 65% PC/35% S mixture.

The rapid chloride permeability test results for the 65% PC/35% S mixture cast in the fall are shown in Figure 3.42. Similar to the slab with the same mixture cast in the summer, the addition of slag resulted in a statistically significant ($p < 0.0040$) reduction charge passed than observed in the fall slab with 100% portland cement (PC). The lab-cured cylinders and cores had coulomb readings within 25% of each other at all ages, except 90 days, when lab-cured cylinders had a charge passed 29% lower than the cores. The readings for the lab-cured cylinders where lower than that of the cores, except at 720 days when the reading for the cores was 8% lower. This difference, however, was statistically significant ($p < 0.028$) at all ages except 360 days. The charge passed of both cylinders and cores decreased with age.

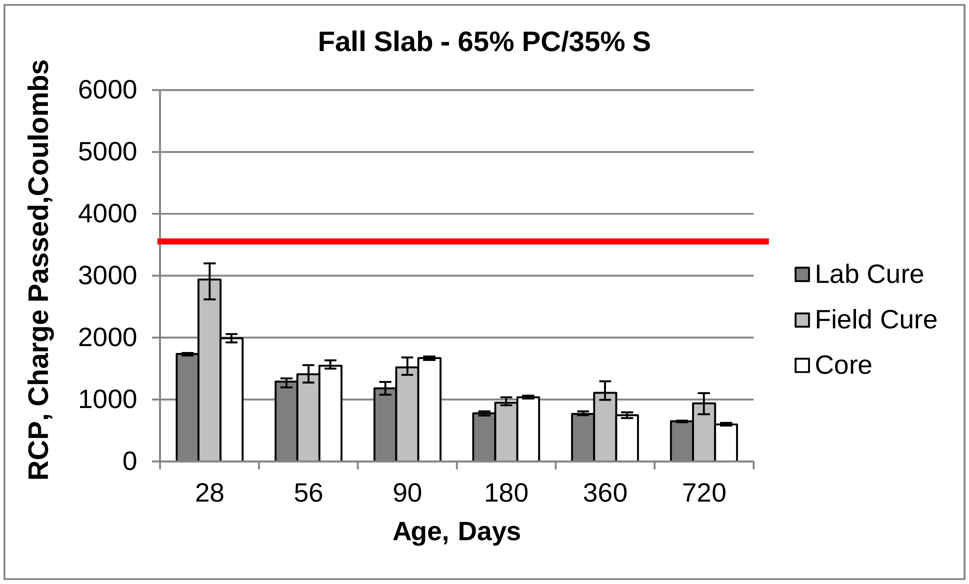

Figure 3.42: RCP test-charge passed fall slab with 65% PC/35% S mixture.

The rapid chloride permeability test results for the 65% PC/35% S mixture cast in the spring are shown in Figure 3.43. As observed for the fall and summer slabs, the addition of slag reduced the charge passed for the slab relative to the spring slab with 100% PC ($p < 0.027$), with all specimens below 3000 coulombs. The charge passed for all specimens decreased with age, with the exception of increases in the field-cured cylinders and cores at 360 days.

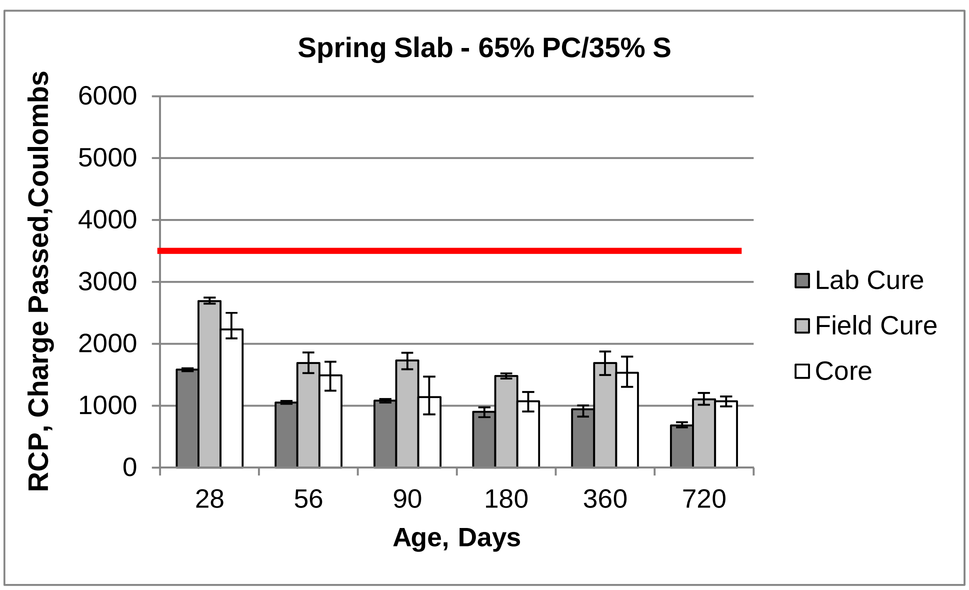

Figure 3.43: RCP test-charge passed for spring slab with 65% PC/35% S mixture.

3.4.3 60% Portland Cement/25% Slag/15% Fly Ash (PC/S/FA) Mixtures

The rapid chloride permeability test results for the 60% PC/25% S/15% FA mixture cast in the summer are shown in Figure 3.44. Again as expected (Wee et al. 2000), this mixture had lower readings (ranging from 740 to 3440 coulombs) than observed in the summer slab with 100% PC (1920 to 4770 coulombs) ($p < 0.098$), but greater values of charge passed than the 65% PC/35% S mixture (720 to 2770 coulombs); in the latter case, however, the differences were not statistically significant. The charge passed for all specimens was below 3500 coulombs. The lab-cured cylinders had lower reading than the cores, but differences that were not statistically significant, except at 180 days and 720 days. The field-cured cylinders had coulomb readings 52% to 121% greater than the lab-cured cylinders at all ages ($p < 0.041$). The charge passed generally decreased with age for all specimen types.

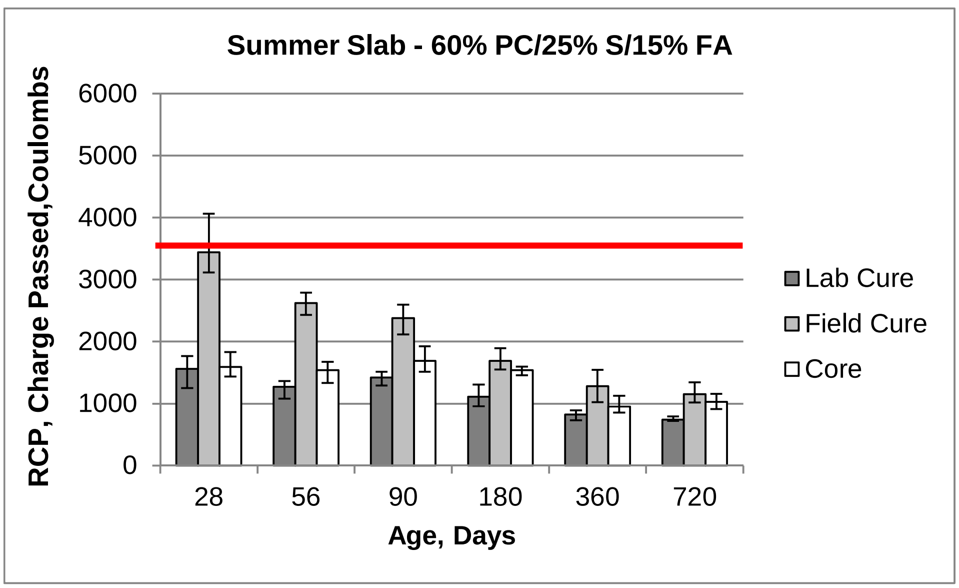

Figure 3.44: RCP test-charge passed for summer slab with 60% PC/25% S/15% FA mixture.

The rapid chloride permeability test results for the 60% PC/25% S/15% FA mixture cast in the fall are shown in Figure 3.45. Similar to the trends observed in the summer slabs, the addition of slag and fly ash resulted in coulomb readings lower ($p < 0.057$) than that of the 100% PC slab cast in the fall and greater ($p < 0.015$) than the 65% PC/35% S slab cast in the fall. The lab-cured cylinders had the lowest average charge passed at all ages ($p < 0.082$). The field-cured cylinders and cores exceeded the 3500 coulomb limit at 28 days, but were within the limit at later ages. The charge passed decreased with age for all specimen types.

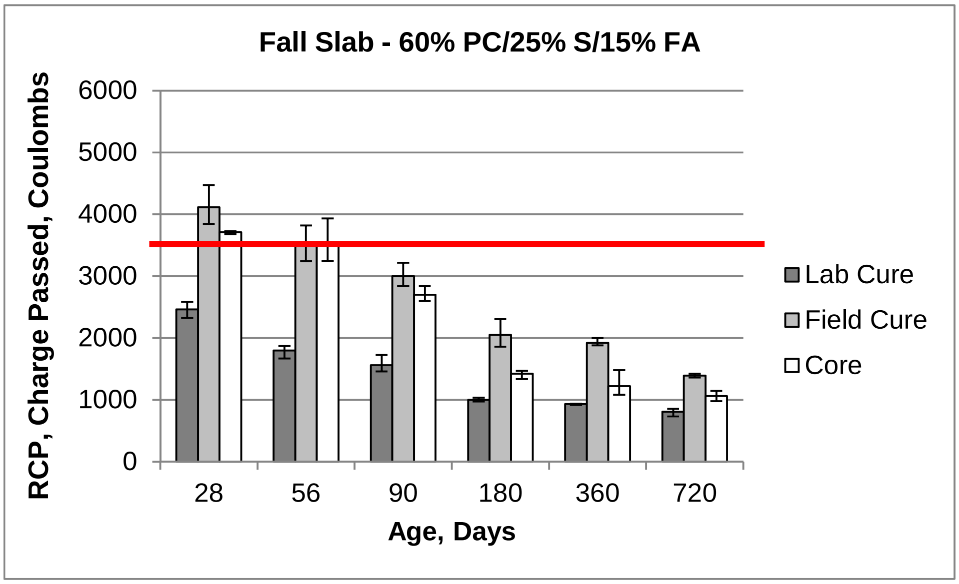

Figure 3.45: RCP test-charge passed for fall slab with 60% PC/25% S/15% FA mixture.

The rapid chloride permeability test results for the 60% PC/25% S/15% FA mixture cast in the spring are shown in Figure 3.46. This slab had the lowest charge passed of all slabs, never exceeding 2000 coulombs. This difference was statistically significant for all slabs with the exception of the spring slab with 65% PC/35% S. As with the other slabs, the charge passed generally decreased with age for all specimen types.

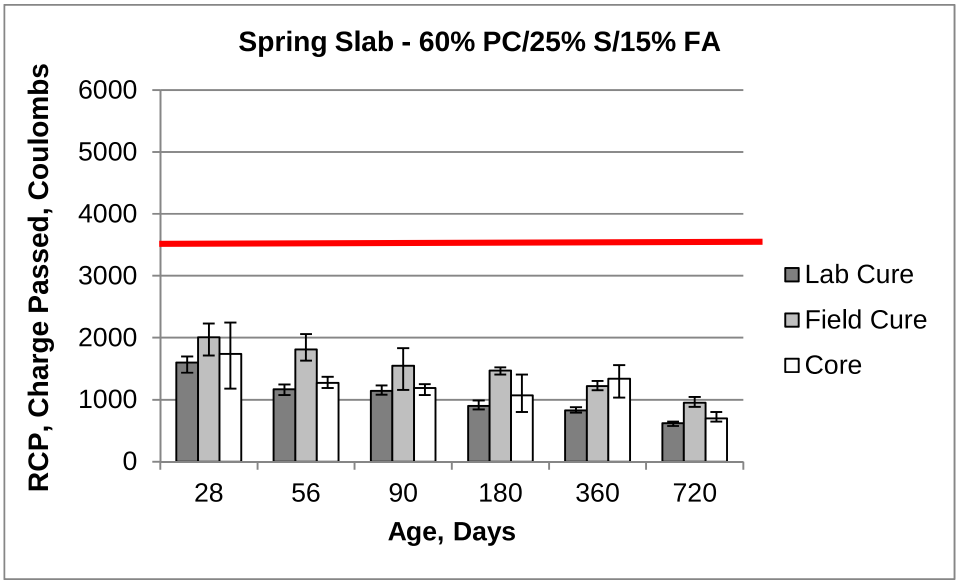

Figure 3.46: RCP test-charge passed for spring slab with 60% PC/25% S/15% FA mixture.

3.4.4 Effect of Plastic Concrete Properties

Figure 3.47 compares actual *w/cm* ratio with the 56-day RCP test results for cores. At a given *w/cm* ratio, mixtures with a SCM had a lower coulomb reading than the 100% portland cement mixture. For the test results shown, however, there appears to be no relationship between charge passed and *w/cm* ratio.

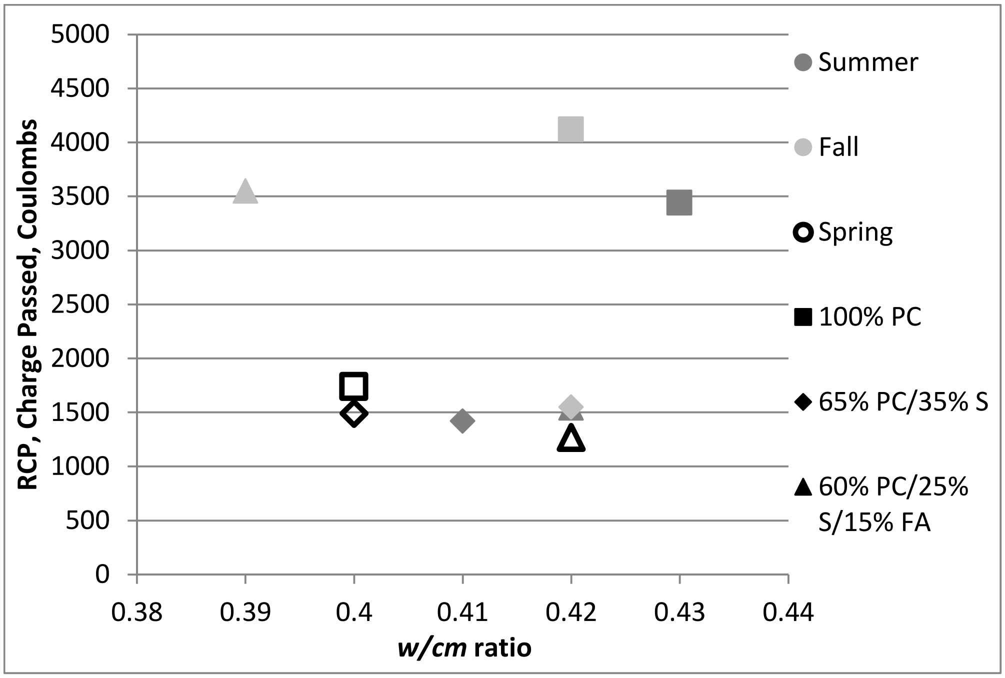

Figure 3.47: 56-day RCP test results (coulombs) vs. *w/cm* ratio.

Figure 3.48 compares concrete temperature at the time of casting with the RCP test results in 56-day cores. No notable trends are observed.

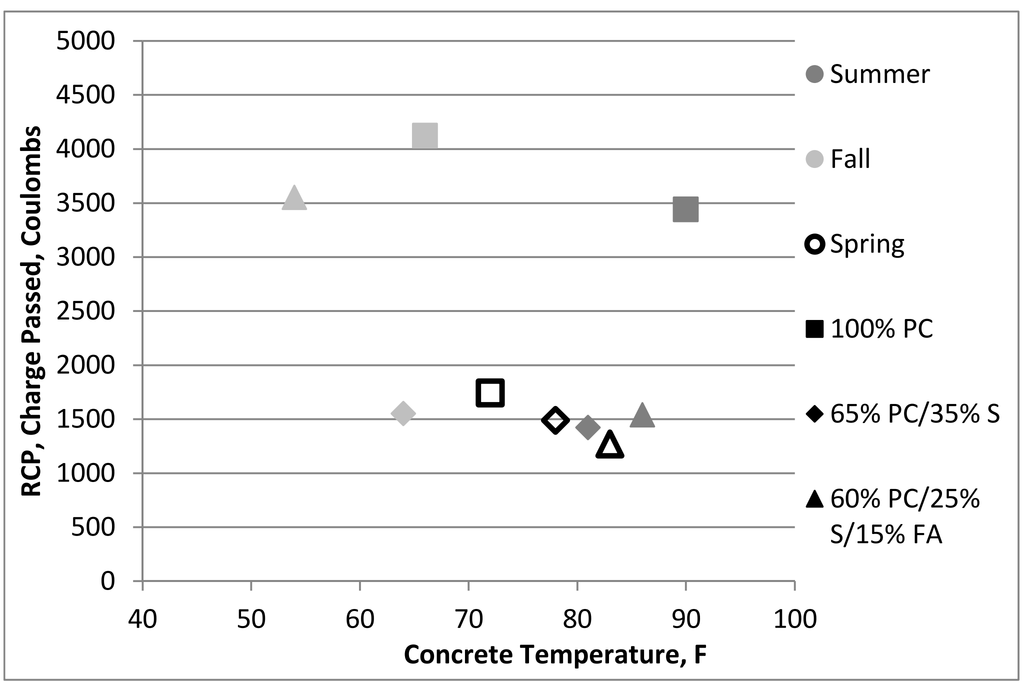

Figure 3.48: 56-day RCP test results (coulombs) vs. concrete temperature at casting.

Figure 3.49 compares air content with the RCP test results for cores at 56 days. For mixtures cast in the summer and fall, an increase in air content coincides with an increase in charge passed. This trend is not observed in the specimens cast in the spring. The slabs with 100% portland cement show an increase in charge passed with increasing air content, while mixtures containing SCMs do not. These comparisons are not adequate to reach any conclusions on the relationship between air content and charge passed.

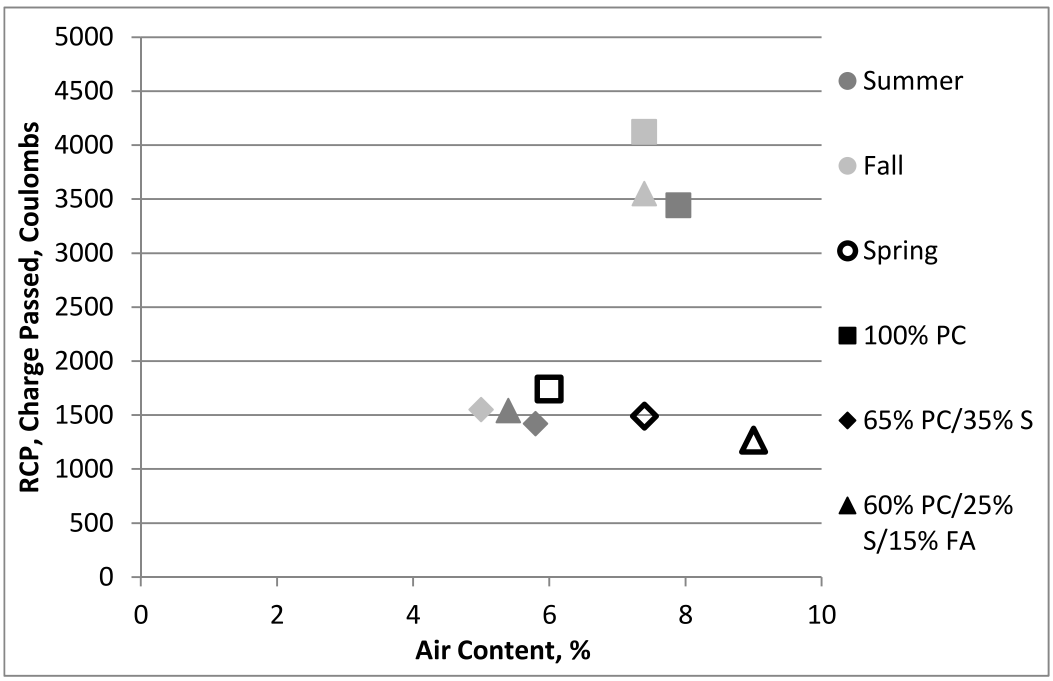

Figure 3.49: 56-day RCP test results (coulombs) vs. concrete air content.

Figure 3.50 compares unit weight with the 56-day RCP results of cores. In general, as the unit weight increases, the percentage of voids decreases. The trend indicates a reduction in charge passed as the unit weight increases. This effect is consistent across mixtures (although all three mixtures with 65% PC/35% S have similar air contents) and summer and fall; however, specimens cast in the spring averaged near 1500 coulombs regardless of unit weight (note that unit weight was not obtained for the summer slab with 60% PC/25% S/15% FA).

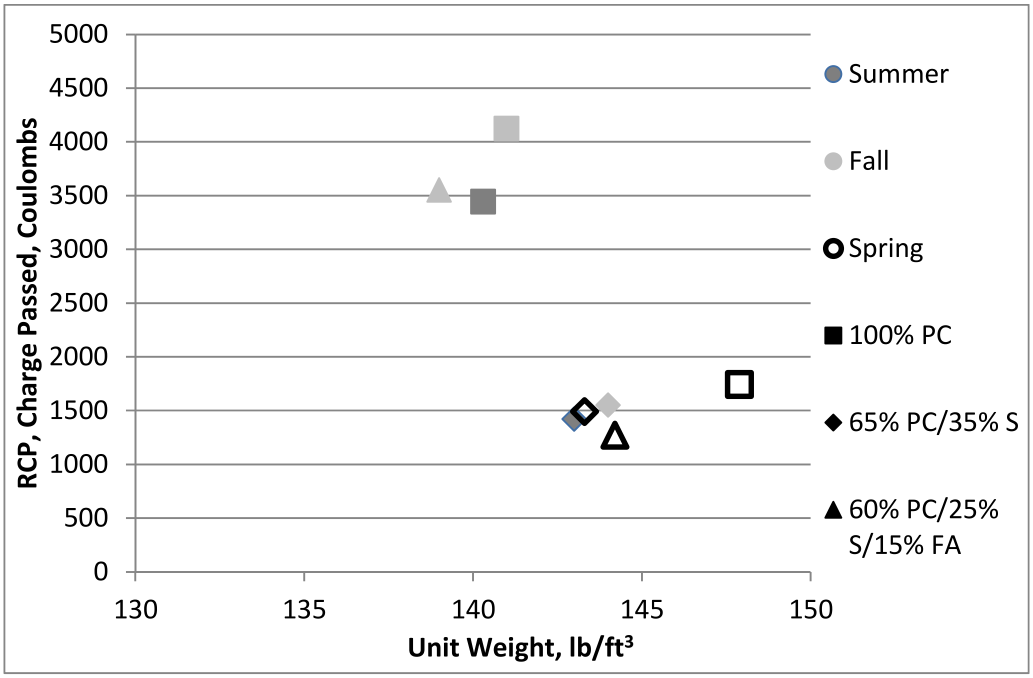

Figure 3.50: 56-day RCP test results (coulombs) vs. unit weight.

3.4.5 Comparison Between Cylinders and Cores

Figure 3.51a shows the ratio of the average charge passed for field-cured cylinders to the average charge passed for lab-cured cylinders for all slabs at all ages. A ratio less than 1.0 indicates that the charge passed for the mixture as measured in the field-cured cylinders was less than that obtained for the lab-cured cylinders. As shown in Figure 3.51a, the charge passed in field-cured cylinders always exceeded that for lab-cured cylinders, with the charge passed in field-cured cylinders sometimes over twice the value found in the lab-cured cylinders. The average ratio of charge passed in field-cured cylinders to lab-cured cylinders was 1.57.

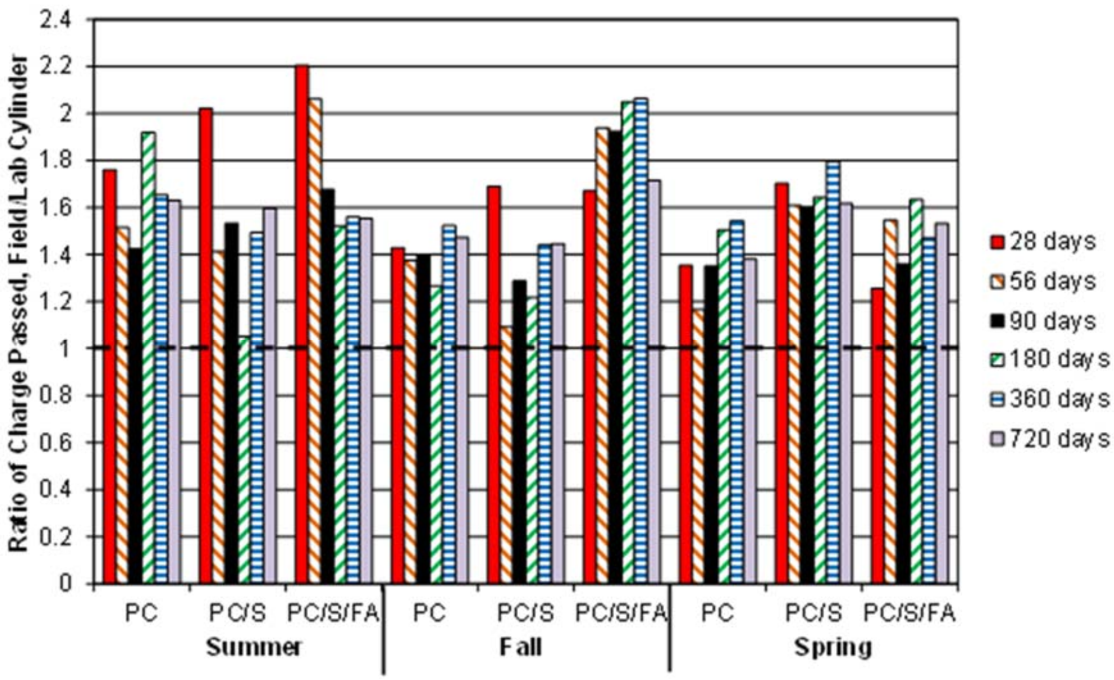

Figure 3.51a: Ratio of charge passed for field-cured cylinders to charge passed for lab-cured cylinders.

Figure 3.51b shows the ratio of the average charge passed for cores to the average charge passed for lab-cured cylinders for all slabs at all ages. The charge passed in cores was frequently (89% of all data points) greater than that for lab-cured cylinders, with the charge passed in cores sometimes over twice the value found in the lab-cured cylinders. The only coulomb readings from cores less than for lab-cured cylinders were for the summer slab with 65% PC/35% S at 180 days, the fall slab with 65% PC/35% S at 360 and 720 days, and the spring slab with 100% PC at 28, 56, and 90 days. The average ratio of charge passed in cores to lab-cured cylinders was 1.34.

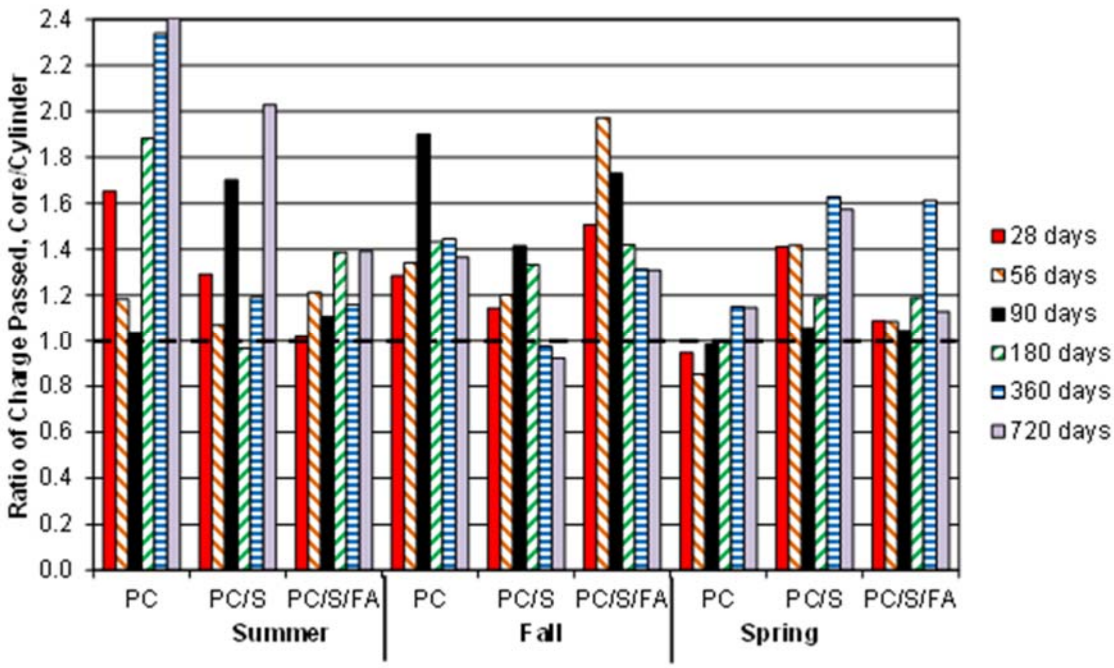

Figure 3.51b: Ratio of charge passed for cores to charge passed for lab-cured cylinders.

Figure 3.51c shows the ratio of average charge passed for cores to average charge passed for field-cured cylinders for all slabs at all ages. Unlike the comparison with the lab-cured cylinders, the charge passed for the cores was frequently (81% of all data points) less than that for the field-cured cylinders. This effect was persistent across all seasons and mixtures. The average ratio of charge passed in cores to field-cured cylinders was 0.87.

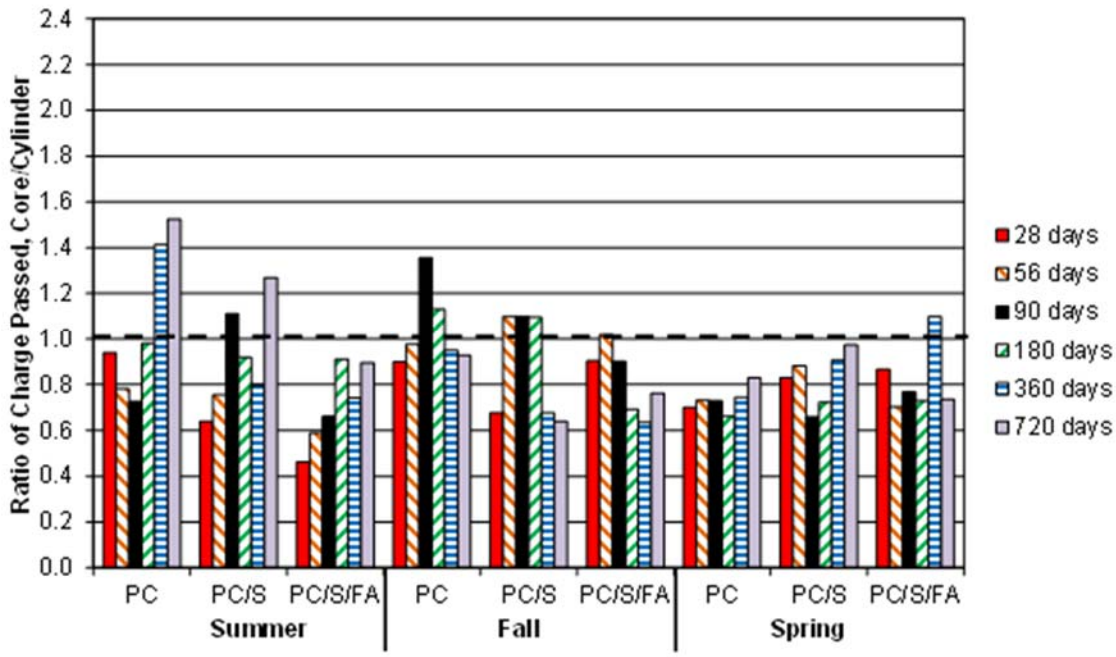

Figure 3.51c: Ratio of charge passed for cores to charge passed for field-cured cylinders.

To establish the statistical significance of the differences observed between lab-cured cylinders, field-cured cylinders, and cores, Student's t-test was performed for all possible pairings of specimens. Differences between cylinder types and cores were considered to be statistically significant if the Student's t-test returns values of α less than 0.10.

Table 3.3 summarizes of the Student's t-test comparisons. Individual comparisons are presented in Tables B.13 through B.18 in Appendix B. As shown in Table 3.3, no lab-cured cylinders had a greater charge passed than the equivalent field-cured cylinders where the difference was statistically significant, whereas 92.6% of field-cured cylinders had a greater charge passed than the lab-cured cylinders where the difference was statistically significant. This is due to the better complete curing conditions provided for the lab-cured cylinders. When comparing lab-cured specimens and cores, only 1.9% of lab-cured cylinders had a greater charge passed than the matching cores where the difference was statistically significant, while 51.9% of cores had a greater charge passed than the cylinders where the difference was statistically significant. For the field-cured cylinders and cores, 46.3% of field-cured cylinders had had a greater charge passed than the matching cores where the difference was statistically significant, compared to just 7.4% of the cores with a greater charge passed than field-cured cylinders with a similar level of statistical significance.

Table 3.3: Percentage of Specimens with Statistically Significant RCP Test Differences

Comparison	Percentage of Specimens
Lab vs. Field	
Lab-cured cylinder greater charge passed	0.0%
Field-cured cylinder greater charge passed	92.6%
Difference not statistically significant	7.4%
Lab vs. Core	
Lab-cured cylinder greater charge passed	1.9%
Core greater charge passed	51.9%
Difference not statistically significant	46.3%
Field vs. Core	
Field-cured cylinder greater charge passed	46.3%
Core greater charge passed	7.4%
Difference not statistically significant	46.3%

3.4.6 Comparison of Results at 56 Days

The charge passed for all slabs at 56 days (the KDOT RCP test age) are shown in Figure 3.52. For all seasons, the 100% portland cement (PC) mixtures had a greater charge passed than either of the mixtures with SCMs. The lab-cured cylinders had the lowest charge passed for all slabs, except for the spring slab with 100% PC, for which the lowest charge passed was obtained for the core. The field-cured cylinders had the highest charge passed for all slabs, except the fall slabs containing SCM's, for which the highest charge passed was obtained in the core tests. The charge passed for the field-cured cylinders for slabs the summer and fall slabs with 100% PC exceeded 3500 coulombs, as it did for the cores from fall slabs with 100% PC and 60% PC/25% S/15% FA. The average 56-day charge passed for the lab-cured cylinders did not exceed 3500 coulombs for any slab.

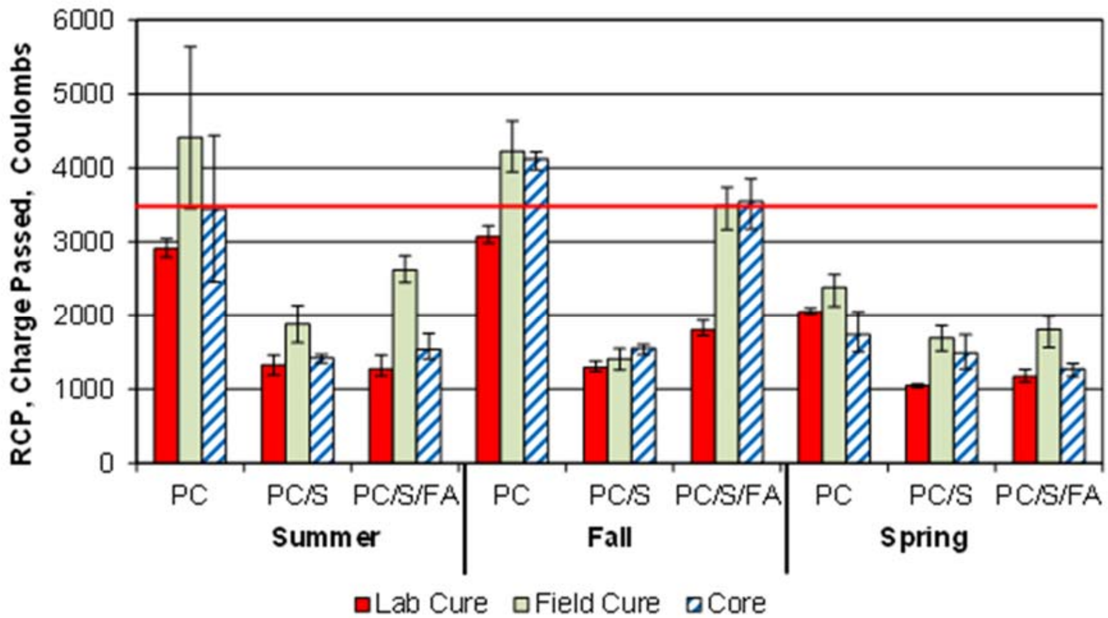

Figure 3.52: RCP test-56 day charge passed.

3.4.7 Comparison between Boil Test and RCP Test Results

Figures 3.53a through 3.53e present comparisons between the average percent voids obtained from the boil test and the average charge passed in the RCP test for all specimen types at all ages. The same data are presented in each figure, with the legend changed to indicate slab, sampling age, sample type (lab-cured cylinder, field-cured cylinder, or core), and mixture type (100% PC, 65% PC/35% S, or 60% PC/25% S/15% FA), respectively, in Figures 3.53a, 3.53b, 3.53c, and 3.53e, and without designation in Figure 3.53d. A horizontal line indicating 12.5% voids for the boil test and a vertical line indicating 3500 coulombs for the RCP test divide the figures into quadrants. Although these limits only apply for lab-cured cylinders at 28 days (boil test) or 56 days (RCP test), they provide a useful reference for all specimens. A data point in the lower left quadrant indicates that the test results met the limits of both the boil test and RCP test, while the test results in the upper right quadrant did not meet the limits for either test. Data in the upper left or lower right quadrant met the limits of one test but not the other.

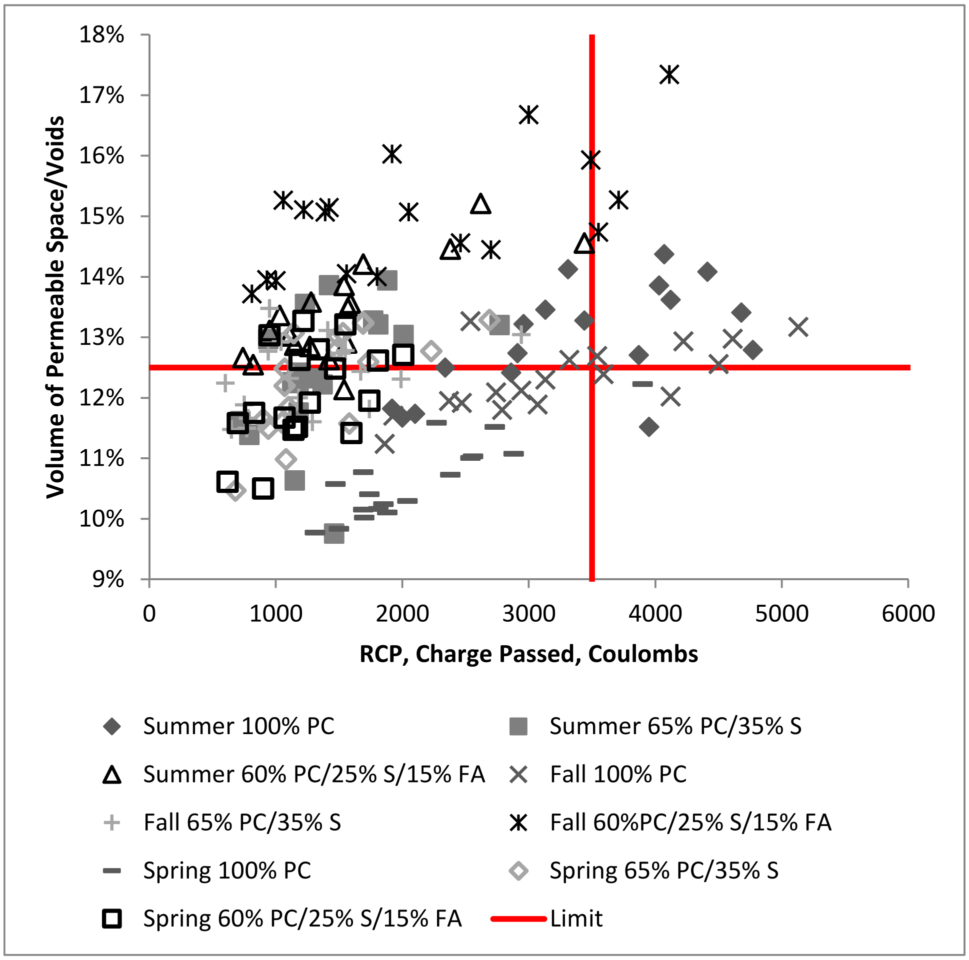

Figure 3.53a: Comparison-Boil Test vs. RCP test with slab type indicated.

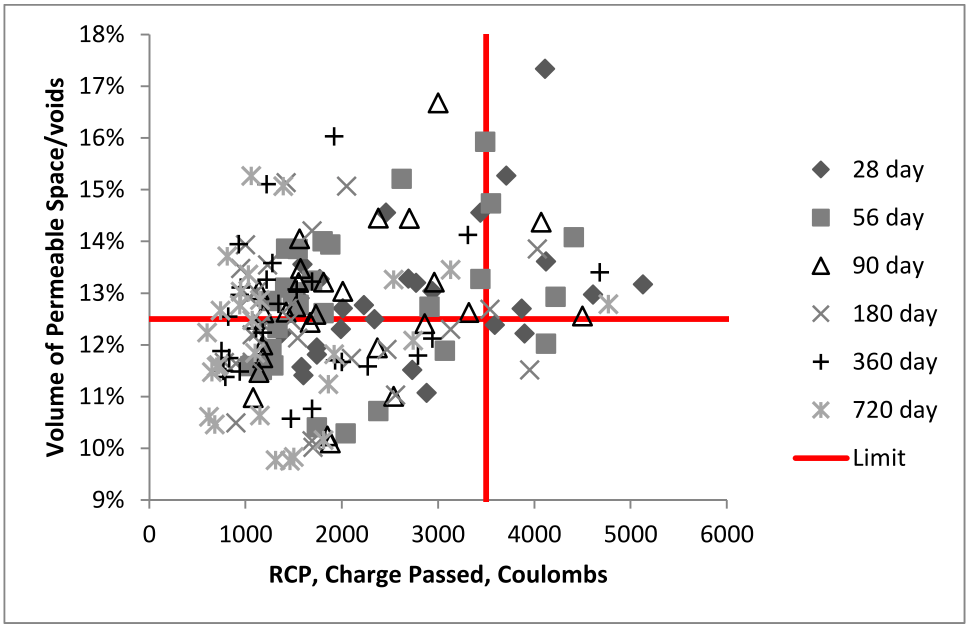

Figure 3.53b: Comparison-Boil Test vs. RCP test with sample age indicated.

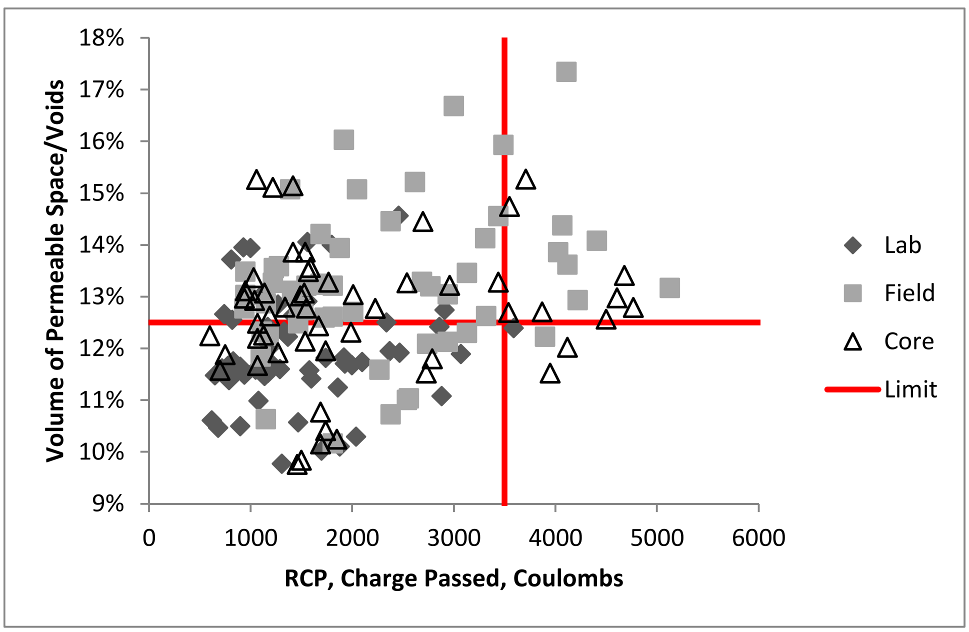

Figure 3.53c: Comparison-Boil Test vs. RCP test with specimen type indicated.

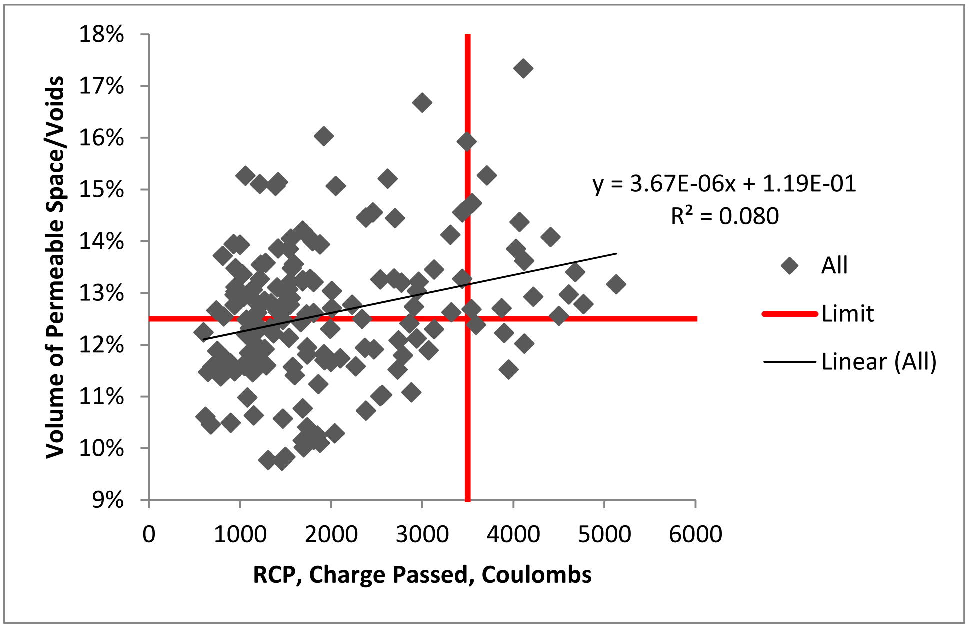

Figure 3.53d: Comparison-Boil Test vs. RCP test with trend line.

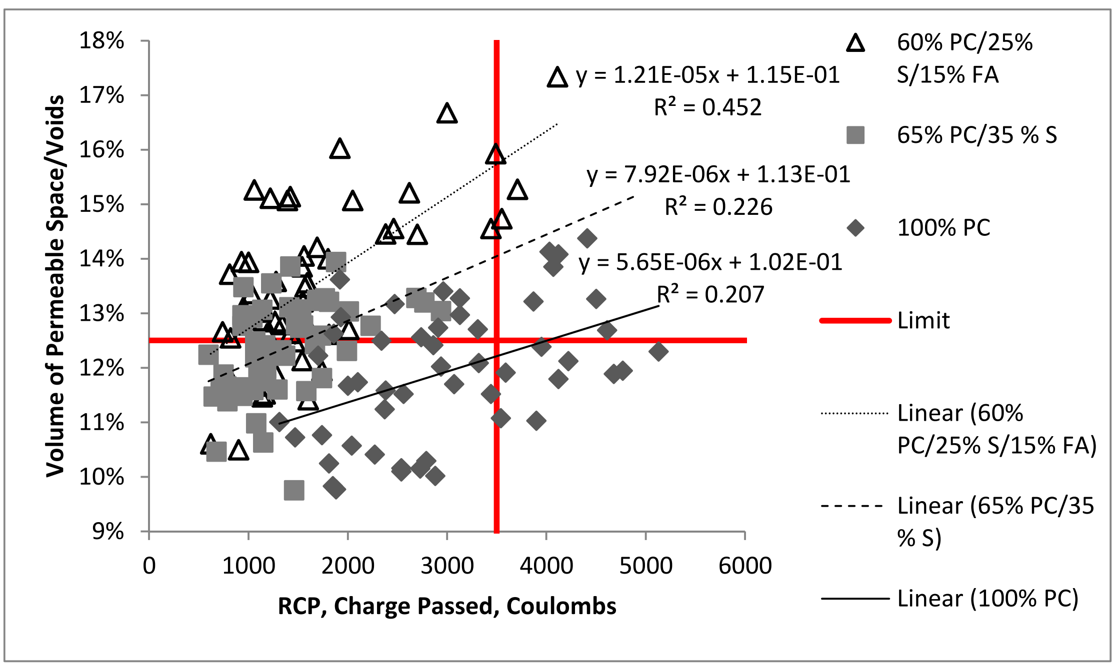

Figure 3.53e: Comparison-Boil Test vs. RCP test with trend lines based on mixture type.

Figure 3.53a shows the results sorted by slab type. Each slab has 18 data points representing the average values from lab-cured cylinders, field-cured cylinders, and cores at each of six ages. For slabs with 100% PC, trend is observed between the boil test and RCP results, showing an increase in voids (boil test) results in an increase in charge passed in the RCP test; furthermore, most (81%) of the data points for these slabs fall in the upper right or lower left quadrants. This indicates that a given specimen is likely to either meet the limits of both tests or exceed the limits of both tests, and suggests that the limits for the two tests correlate well for 100% portland cement mixtures. However, the large scatter in the data indicates that while the limits may be reasonably well correlated for 100% PC mixtures, the overall test results are not.

The accuracy of these tests is significantly reduced for mixtures containing SCMs. Many of the SCM mixtures show reductions in charge passed in the RCP test that are not reflected in a reduction in voids in the boil test (data points in the upper left quadrant). The fall slab with 60% PC/25% S/15% FA, for example, only had 3 of 18 specimens average over 3500 coulombs in the RCP test, but all 18 specimens exceeded 12.5% for the boil test. This lack of correlation is not surprising, as the RCP and boil tests measure different properties of concrete. The RCP test, which measures charge passed under exposure to a chloride solution, is a measure of ion conductivity, while the boil test is a measure of porosity. There is nothing inherent in the two concrete properties measured that would suggest that they are correlated. In spite of this fact, both tests are used to represent concrete quality and to qualify concrete mixtures in the field.

Figure 3.53b shows the results sorted by specimen age. Although much variation is present in the data, both the void content as measured by the boil test and the charge passed in the RCP test tend to decrease with age; the specimens tested at 720 days have the lowest values for both the boil and RCP tests, with 59% of data points in the lower left quadrant (met the limits of both tests) and only 3.7% of data points in the upper right quadrant (exceeded the limits of both tests). The highest values recorded in both the boil and RCP tests belong to the specimens tested at 28 days. The 28-day specimens have 33% of data points in the lower left quadrant and 22% of data points in the upper right quadrant.

Figure 3.53c shows results sorted by specimen type. As described in the individual slab results, the field-cured specimens had the highest values in both the boil and RCP tests (13% of data points in the upper right quadrant, 20% of data points in the lower left quadrant), while the lab-cured specimens had the lowest values (0% of data points in the upper right quadrant, 74% of data points in the lower left quadrant). Cores had boil and RCP test values between those of the lab-cured and field-cured cylinders, with 15% of data points in the upper right quadrant and 37% of data points in the lower left quadrant. This strongly suggests that lab-cured cylinders will yield test results for the boil and RCP tests that will be lower than will be obtained from in-place concrete, whereas testing field-cured cylinders will yield values that will greater than obtained from in-place concrete.

Figure 3.53d shows all results with a best-fit trend line to establish the overall correlation between boil test and RCP test results. Overall, the trend line indicates low correlation between tests ($R^2 = 0.08$). For all data points, 9% fell in the upper right quadrant and 45% fell in the lower left quadrant, meaning that the limits set for the boil test and RCP test were in agreement only 54% of the time, slightly better than random chance. This further demonstrates a low correlation between boil test and RCP test results.

Figure 3.53e shows all data with a trend line fit to each mixture type. The correlation coefficients are still low ($R^2 = 0.452$ for the 60% portland cement/25% slag/15% Class C fly ash mixtures, $R^2 = 0.226$ for the 65% portland cement/35% slag, and $R^2 = 0.207$ for the 100% portland cement mixtures), but are significantly better than obtained for all of the data ($R^2 = 0.08$), as described for Figure 3.60d. Based on Figure 3.60e, it is clear that for a given charge passed in the RCP test, the mixtures containing SCM's have a greater percentage of permeable space/voids in the boil test than the 100% PC mixtures. Furthermore, the slope of the trend lines for the mixtures with SCMs is greater than the 100% PC mixtures, indicating the disparity in results becomes worse for higher values of charge passed.

3.5. Laboratory Specimen Results

The purpose of the laboratory specimens was to compare boil test and RCP test results to a direct measurement of chloride permeability by determining the diffusion coefficient for the slabs. Three mixtures were cast with varying air contents, 9.15%, 7.65%, and 5.9%, each with 100% portland cement. The results for each test are presented individually (Sections 3.5.1 – 3.5.3), with a comparison in Section 3.5.4. The data for laboratory tests are given in Appendix D.

3.5.1 Boil Test Results

The results from the boil test at all ages are presented in Figure 3.54. All samples were lab-cured cylinders. For specimens that were cured for 28 and 56 days, the percentage of voids decreased as the air content decreased, although the effect was minor (less than 5% difference between specimens) and not statistically significant. For specimens that were cured for 90 days, the specimens with 5.9% air content had the lowest percentage of voids, but the mixture with the intermediate air content had a higher percentage of voids than the mixture with the high air content. The differences in voids after 90 days of curing were statistically significant ($p < 0.086$). The mixtures had test results between 11% and 12%.

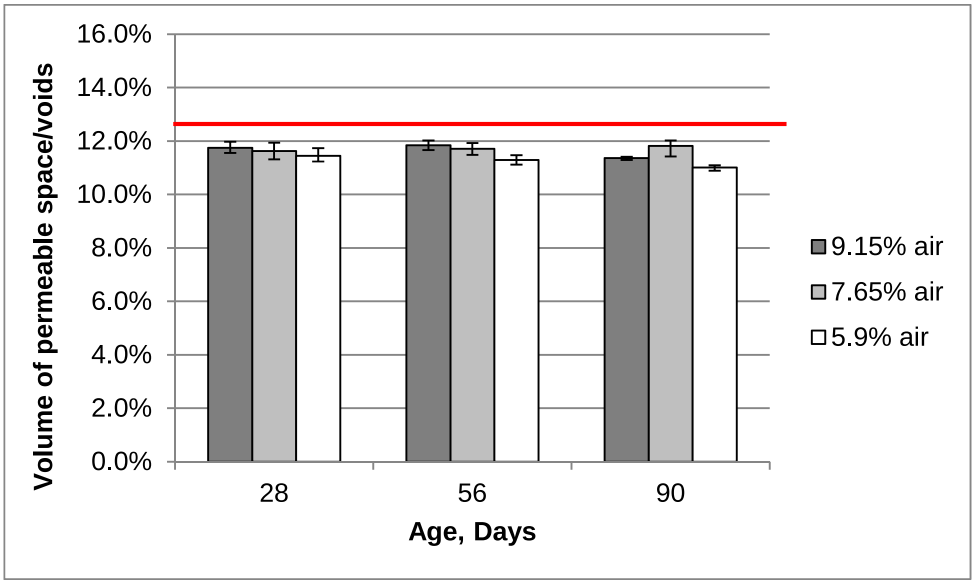

Figure 3.54: Boil test results for laboratory specimens.

3.5.2 RCP Test Results

The results of the RCP test at all ages are presented in Figure 3.55. At all curing ages, the charge passed decreased as the air content decreased. This effect was much greater than the differences observed in the boil test (Fig. 3.54). The differences between the mixture with 9.15% air and the other two mixtures was statistically significant at all ages ($p < 0.053$). All mixtures had test results that averaged less than 3500 coulombs, and specimens tested at later ages had lower amounts of charge passed than those tested after 28 days.

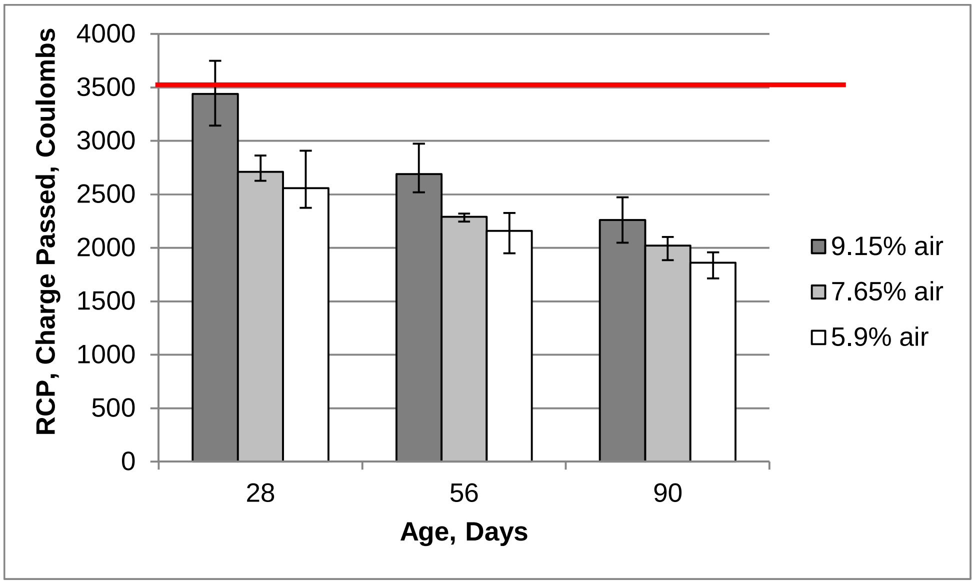

Figure 3.55: RCP test results for laboratory specimens.

3.5.3 Diffusion Results

Figures 3.56a, 3.56b, and 3.56c show the chloride content vs. depth for the laboratory specimen tests in accordance with AASHTO T 259 after 28 days, 56 days, and 90 days of curing, respectively. The chloride content at each depth represents the average of three specimens (each sampled using three cores); error bars give the range of data based on the average chloride content for each specimen. The specimens cured for 28 days had similar values at all depths, with the exception that the specimens with 5.9% air content exhibited the lowest chloride content at the shallowest sampling depth. For the specimens cured for 56 and 90 days (Figures 3.63b and c), the specimen with 5.9% air content also had a lower chloride content at most sampling depths.

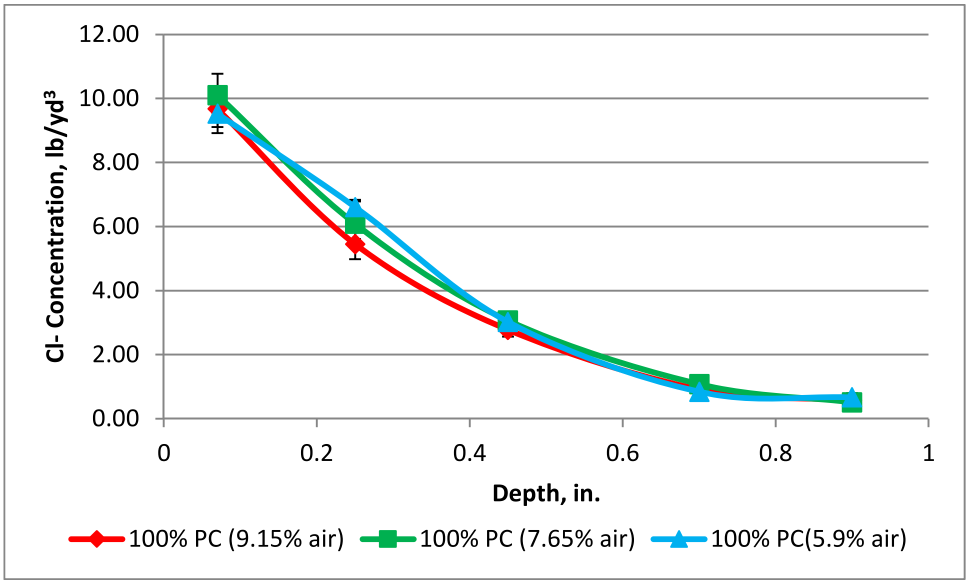

Figure 3.56a: Chloride concentration vs. depth for laboratory specimens with 28 days of curing

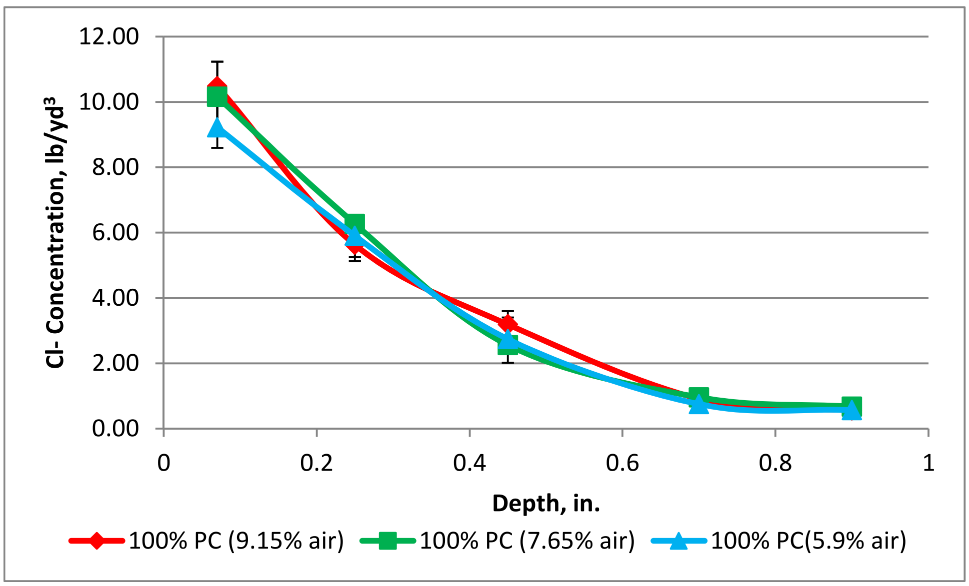

Figure 3.56b: Chloride concentration vs. depth for laboratory specimens with 56 days of curing.

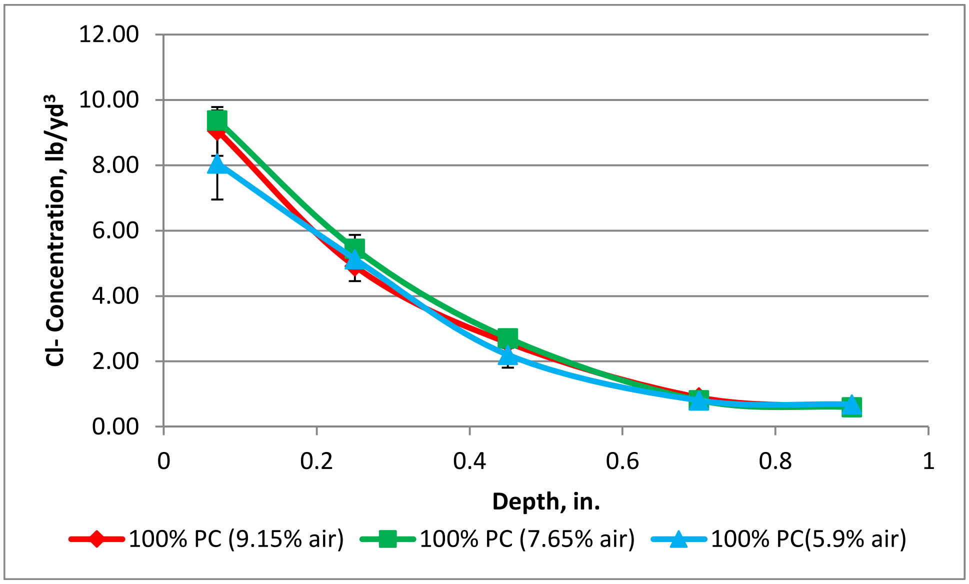

Figure 3.56c: Chloride concentration vs. depth for laboratory specimens with 90 days of curing.

Based on the chloride profiles shown in Figures 3.56a, 3.56b, and 3.56c, diffusion coefficients D_{eff} were calculated for each mixture and curing age using the solution to Fick's Second Law based on the average chloride concentration at each depth, as described in Section 2.5.2. Initial calculations identified difficulties in accurately matching the chloride contents at deeper depths (0.6 to 0.8 in. and 0.8 to 1.0 in.). To solve this problem, the chloride content at 0.8 to 1.0 in. was treated as a "background" chloride value for the purposes of determining the diffusion coefficient; this value was subtracted from the chloride content at all depths for the analysis. After analysis, the background chloride value was added back to the surface chloride concentration and the chloride contents at all depths (the diffusion coefficient remained unchanged).

The solution also produced a value for the surface chloride concentration C_o for each mixture and curing age. The values of D_{eff} and C_o are summarized in Table 3.4. As shown in Table 3.4, the values of D_{eff} varied significantly from the expected values (Mindess et al. 2003) – D_{eff} uniformly highest for the mixture with the lowest, rather the highest, air content largely because the values of C_o were lowest for the mixture with the lowest air content, which mathematically forced higher values of D_{eff}. To correct this weakness in the solution, the values of D_{eff} were recalculated using the average of the values of C_o obtained in the initial analysis, 11.26 lb/yd^3. The diffusion coefficients from the second analysis, presented in Figure 3.57 and Table 3.5, indicate that, with the exception of the specimens with 9.15% air and 28-day curing, the diffusion coefficients, and thus permeability, decreased as curing time increased. For specimens with 56 and 90 days of curing, the specimens with the lowest air content (5.9%) also had the lowest diffusion coefficient. This trend was not observed at 28 days, however, again because of the low value of D_{eff} obtained for the specimens with 9.15% air. It is likely that this low value is due to scatter in the chloride data.

Table 3.4: Diffusion Coefficients and Surface Chloride Concentrations–Initial Analysis

Specimen		Curing Time (days) 28	56	90
9.15% air	D_{eff} (in.^{2}/day)	6.46E-04	6.55E-04	5.99E-04
	C_o (lb/yd^3)	11.39	12.25	10.69
7.65% air	D_{eff} (in.^{2}/day)	7.43E-04	6.31E-04	6.50E-04
	C_o (lb/yd^3)	11.83	12.17	11.08
5.9% air	D_{eff} (in.^{2}/day)	7.80E-04	7.17E-04	6.42E-04
	C_o (lb/yd^3)	11.37	10.96	9.64

Table 3.5: Diffusion Coefficients and Surface Chloride Concentrations–Final Analysis

Specimen		Curing Time (days) 28	56	90
9.15% air	D_{eff} (in.^{2}/day)	6.60E-04	7.69E-04	5.39E-04
	C_o (lb/yd^3)	11.26	11.26	11.26
7.65% air	D_{eff} (in.^{2}/day)	8.15E-04	7.29E-04	6.30E-04
	C_o (lb/yd^3)	11.26	11.26	11.26
5.9% air	D_{eff} (in.^{2}/day)	7.94E-04	6.83E-04	4.72E-04
	C_o (lb/yd^3)	11.26	11.26	11.26

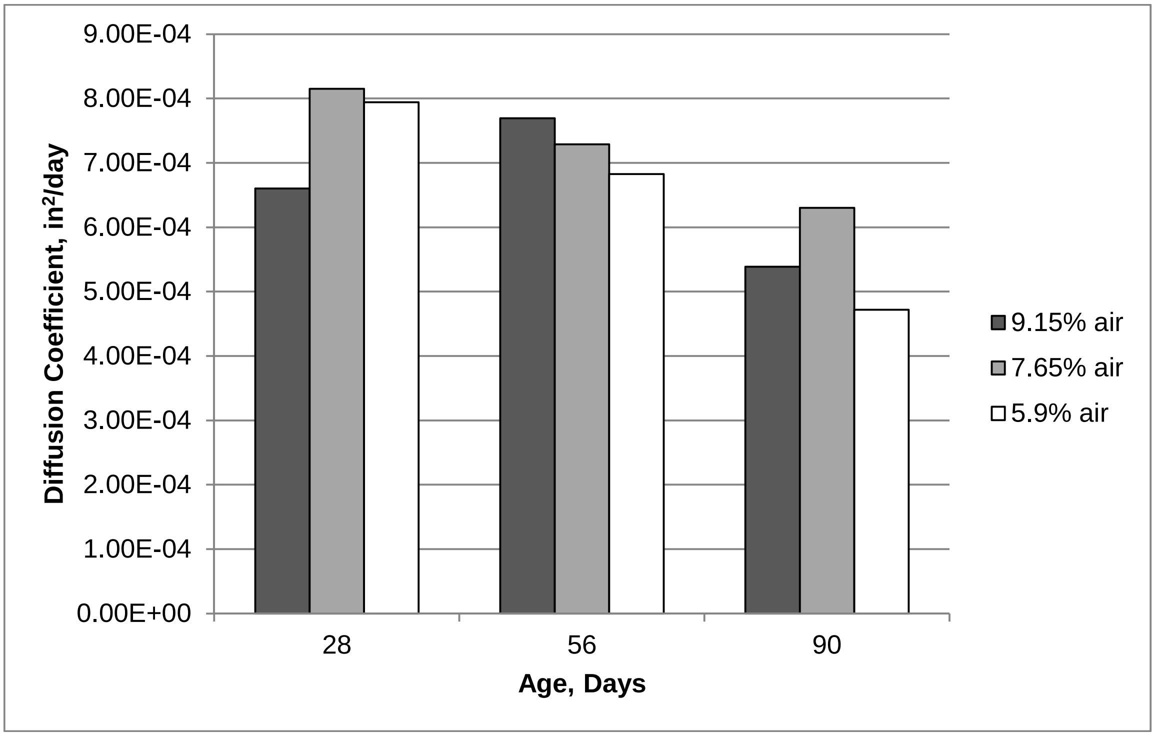

Figure 3.57: Diffusion coefficients for laboratory mixtures.

3.5.4 Comparison Between Diffusion Coefficient and Boil Test/RCP Test

Figure 3.58 compares the boil test results with the diffusion coefficients for laboratory specimens. For the mixtures with air contents of 5.9% and 9.15%, the diffusion coefficient increases as the (boil test) void content increases. For the mixtures with an air content of 7.65%, however, the diffusion coefficient *decreases* as the void content increases, providing additional support that the porosity as measured by the boil test does not correlate with permeability.

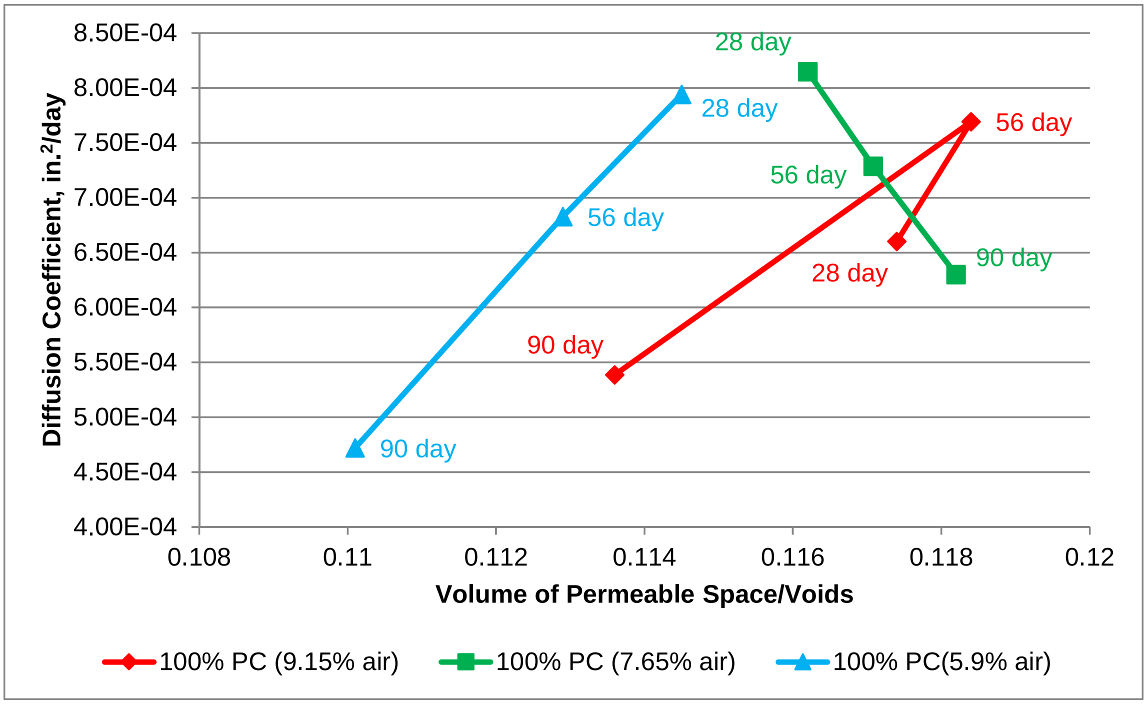

Figure 3.58: Comparison between diffusion coefficient and volume of voids from boil test for laboratory specimens.

Figure 3.59 compares the RCP test results with the diffusion coefficients for the laboratory specimens. With the exception of the specimens with 9.15% air and 28-day curing, all three mixtures show very good individual correlation between the charge passed and diffusion coefficient, with both the charge passed and the diffusion coefficient decreasing with an increase in curing time at near proportional rates. Furthermore, the RCP test appears to have good repeatability in predicting the diffusion coefficients – the data for the mixtures with 7.65% and 5.9% air contents fall on a single curve, and the data for the mixture with 9.15% air, excluding the data point for specimens with a 28-day cure, is close to that of the other mixtures. Although additional research will be needed to establish a clear trend, these results suggest there may be a direct relationship between charge passed in an RCP test and diffusion coefficient for a given mixture without supplementary cementitious materials.

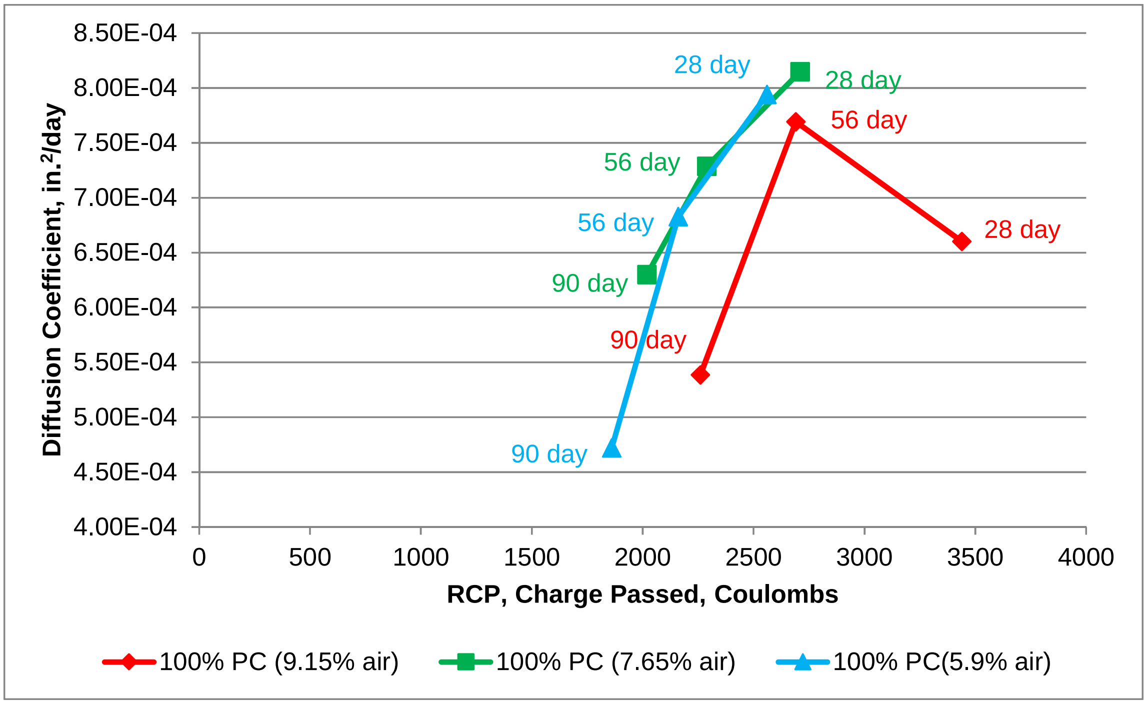

Figure 3.59: Comparison between diffusion coefficient and RCP test results for laboratory specimens.

3.6 Discussion

The results presented in this report exhibit a large degree of scatter; this scatter was particularly noticeable in the compressive strength results. Much of the observed behavior that ran contrary to expectation (that is, drops in strength, increases in permeability, or increases in porosity with time) is likely due to this scatter and does not represent a statistically significant trend. Many factors are likely responsible for the scatter. Much of the scatter observed is due to the inherently variable nature of concrete; significant variation, including decreases in average compressive strength over time, were observed by Malisch and Suprenant (2013) and others. As each test was the average of only three cylinders, individual results may vary considerably from expected behavior. At later ages, when the changes in concrete properties are relatively small and more readily overshadowed by statistical variation, this is especially true. Additional variation was also introduced by having multiple personnel molding cylinders for each slab; a necessity given the large number of cylinders molded with each slab (122), but one that introduced the possibility of uneven consolidation. Cylinders were picked for testing from different portions of the batch to minimize this effect, but its influence could not be eliminated. Finally, the relatively low slump (0.75 in.) used in the spring slab with 100% portland cement resulted in difficulties during consolidation of some of the cylinders. Every effort was made to avoid testing cylinders with visible honeycombing, but some of the behavior observed in this slab was likely due to these issues.

CHAPTER 4: SUMMARY AND CONCLUSIONS

4.1 Summary

Questions have arisen in practice about how concrete systems gain strength over time, and the relationship between in-field concrete conditions and those derived from cylinder tests. Time and curing conditions may impact the strength and permeability of concrete. These issues are of special concern for mixtures containing supplementary cementitious materials (SCMs), some of which hydrate more slowly than portland cement. This research investigated the strength and permeability behavior of concrete over time with and without supplementary cementitious materials.

Three concrete mixtures were evaluated, a control mixture with 100% portland cement, a mixture with 35% replacement (by weight) with slag cement, and a mixture with 15% replacement with Class C fly ash and 25% replacement with slag. Slabs containing each mixture were cast in the summer, fall, and spring, along with companion 4 × 8 in. cylinders, to determine the effect of seasonal variations in environmental conditions on the strength and permeability of concrete. Cylinders were cured in both the laboratory and the field, and cores were taken from each slab. Specimens were evaluated for compressive strength, void content using the boil test, and ionic conductivity using the rapid chloride permeability (RCP) test at ages of 28, 56, 90, 180, 360, and 720 days.

4.2 Observations

1. During the first 24 hours, the concrete in a pavement slab usually attained a higher temperature than either the air or the tests cylinders curing on site. In some cases, however, cylinders in direct sun had a higher temperature.

2. The concrete in field-cured cylinders was subjected to a wider temperature range, both high and low, than the concrete in pavement slabs. When exposed to direct sunlight, the temperature of cylinders was higher than the air temperature.
3. At the same total cementitious material content, concrete containing slag cement or slag cement and fly ash exhibited a lower temperature rise during the first 24 hours than concrete containing no supplementary cementitious material.
4. In a large majority of cases, 93% and 81%, respectively, the compressive strengths of lab-cured cylinders exceeded the compressive strengths of companion field-cured cylinders and cores taken from the pavement slabs.
5. In a large majority of cases (76%), the compressive strengths of cores taken from the pavement slabs exceeded the compressive strength field-cured cylinders.
6. Concrete strength, as evidenced by the 28-day compressive strength of cores, tended to decrease as the temperature of the concrete at the time of casting and the early curing temperatures on site deviated above or below 70 °F. This was especially true for the 60% portland cement/25% slag/15% Class C fly ash mixture. The longer-term strength of concrete cast in cold weather was comparable to that of concrete cast in moderate temperatures.
7. When the results were averaged across concrete cast in all seasons, all three mixtures exhibited an increase in compressive strength between 28 and 720 days for all three specimen types, but the strength increase was monotonic only for the 60% portland cement/25% slag/15% Class C fly ash mixture. The 65% portland cement/35% slag mixtures exhibited a decrease in compressive strength between 360 and 720 days (between 180 and 720 days for lab-cured cylinders). The 100% portland cement mixtures exhibited a decrease in strength between 360

and 720 days for lab-cured cylinders and cores and between 56 and 180 days for field-cured cylinders.

8. Compressive strength at 28 days increases as the air content, as represented by the air content and unit weight of plastic concrete, decreases. The unit weight of the concrete is the more consistent guide to compressive strength.
9. The percentage of voids measured using the boil test decreased as the unit weight, a measure of air content, increased. There was no apparent relationship, however, with the air content of the plastic concrete. The void content decreased with specimen age.
10. The percentage of voids measured using the boil test was consistently lower in lab-cured specimens than in field-cured specimens (all cases) and cores (93% of cases), and lower in cores than in field-cured specimens (83% of cases). Temperatures deviating from 70 °F were deleterious to void content in field-cured specimens and cores.
11. The charge passed measured using the Rapid Chloride Permeability (RCP) test generally decreased as the unit weight, a measure of air content, increased. There was no apparent relationship, however, with the air content of the plastic concrete. The charge passed decreased with specimen age.
12. The charge passed measured using the Rapid Chloride Permeability (RCP) test was consistently lower in lab-cured specimens than the in field-cured specimens (all cases) and cores (89% of cases), and lower in cores than in field-cured specimens (81% of cases).
13. The results for the boil test and the RCP test correlated fairly well for the 100% portland cement mixtures. They do not correlate well for the two mixtures containing supplementary cementitious materials (SCMs) as the latter exhibit higher void contents, but lower values of charge passed.

14. For a single mixture containing no SCMs, the results of the boil test did not correlate with the diffusion coefficient obtained using AASHTO T 259 “Standard Method of Test for Resistance of Concrete to Chloride Ion Penetration.”

15. For a single mixture containing no SCMs, the results of the RCP test correlated with the diffusion coefficient obtained using AASHTO T 259 “Standard Method of Test for Resistance of Concrete to Chloride Ion Penetration” in most cases.

4.3 Conclusions

The following conclusions are based on the results of the research summarized above.

1. Concrete subjected to either hot or cold weather may exhibit lower strength and higher permeability. Mixtures containing fly ash tend to be more affected by lower temperature at early ages. The use of SCMs, however, mitigates some of the effects of hot weather.

2. Field-cured cylinders underestimate the quality of concrete, as delivered, exhibiting lower strengths and higher permeability than observed in cores taken from slabs or lab-cured cylinders.

3. Lab-cured cylinders tend to have higher strength and lower permeability than cores taken from pavement slabs.

4. Based on a poor correlation between boil test results and both the charge passed in the RCP test and diffusion coefficients measured from ponding tests, the boil test, as expected, does not appear to provide an accurate means of determining permeability of concrete.

5. Concrete strength may decrease with time, as consistently observed between 360 and 720 days for the mixtures containing slag cement.

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APPENDIX A: TEMPERATURE PROFILES

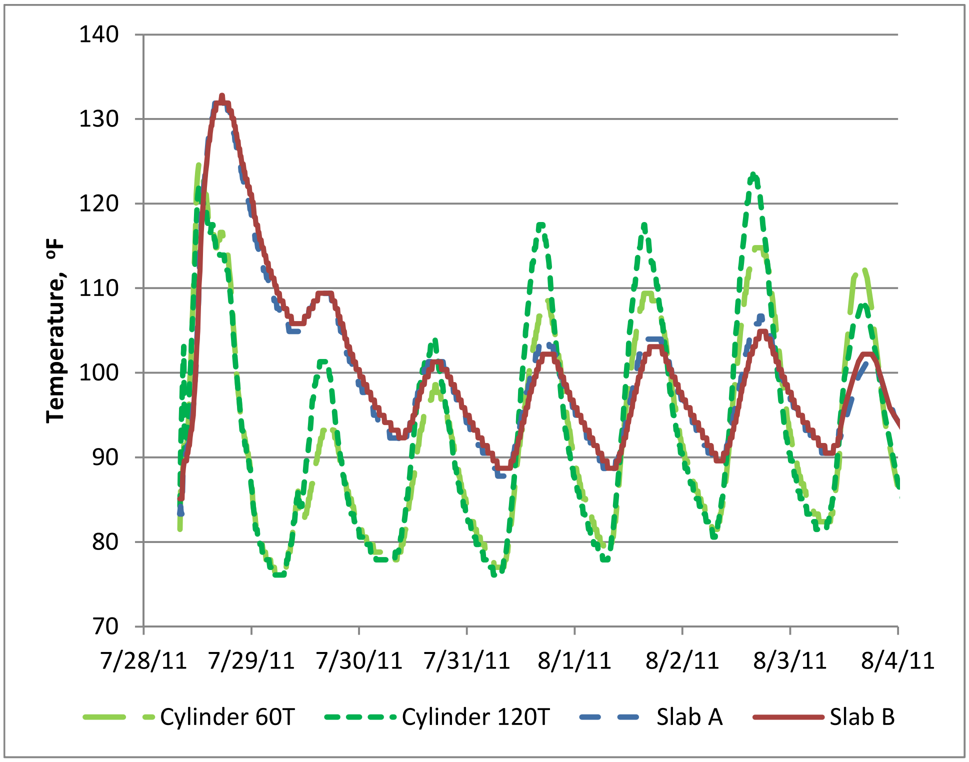

Figure A.1a: Temperature vs. time for summer slab with 100% portland cement (PC) mixture.

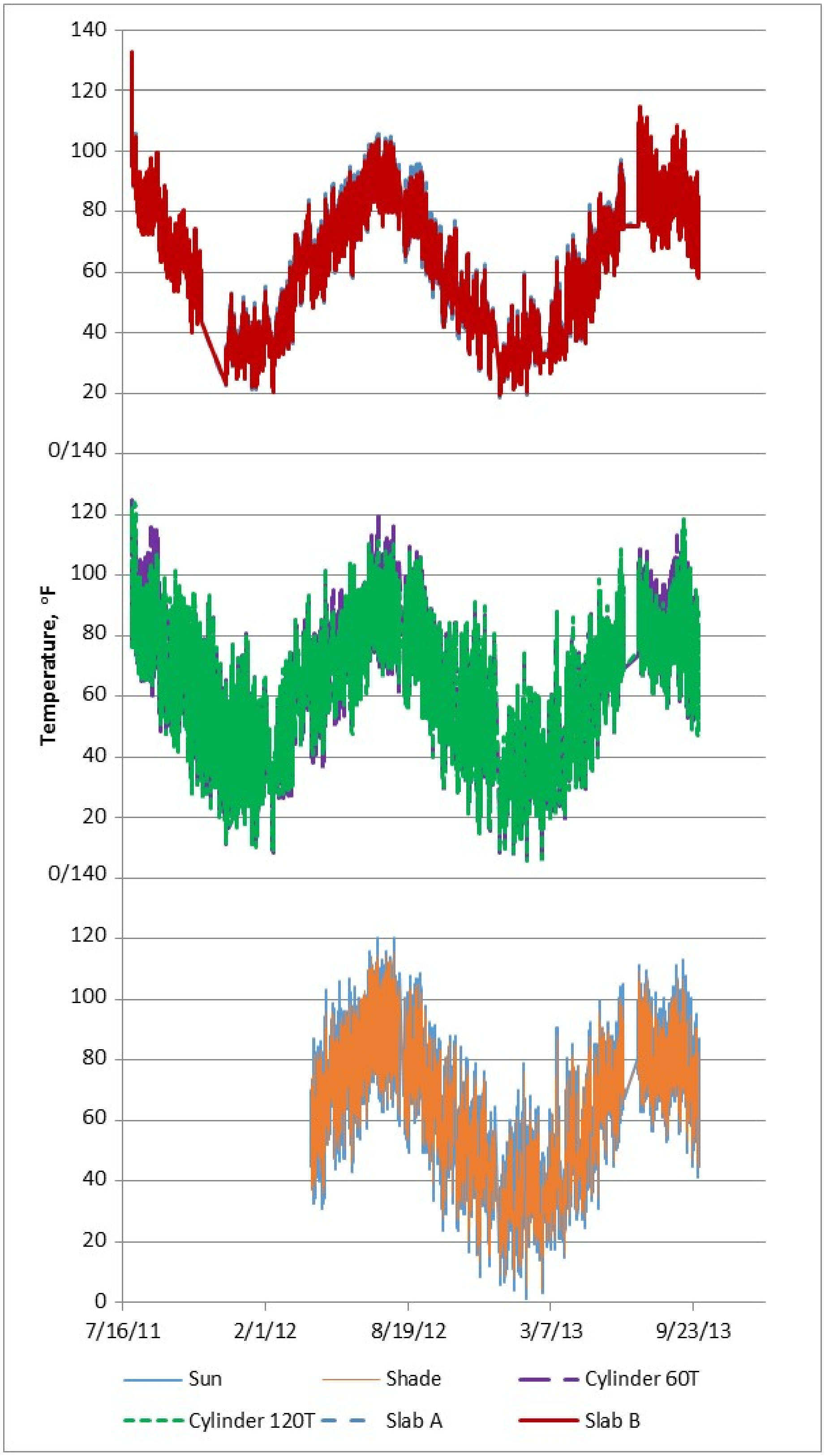

Figure A.1b: Temperature vs. time for summer slab with 100% portland cement (PC) mixture (different range).

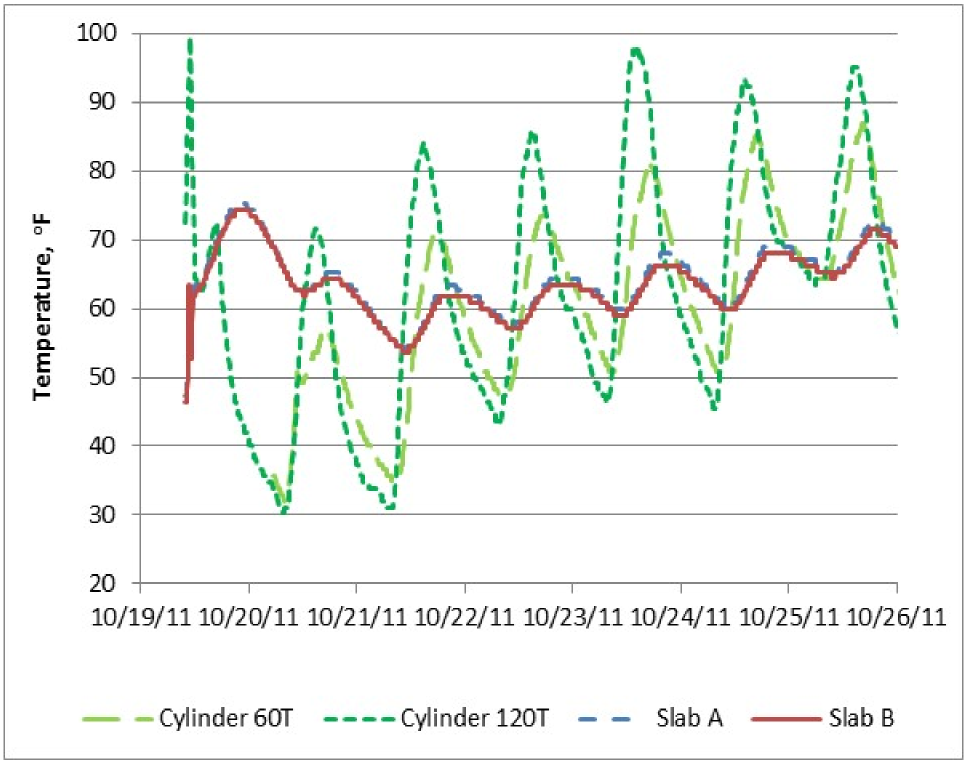

Figure A.2a: Temperature vs. time for fall slab with 100% portland cement (PC) mixture.

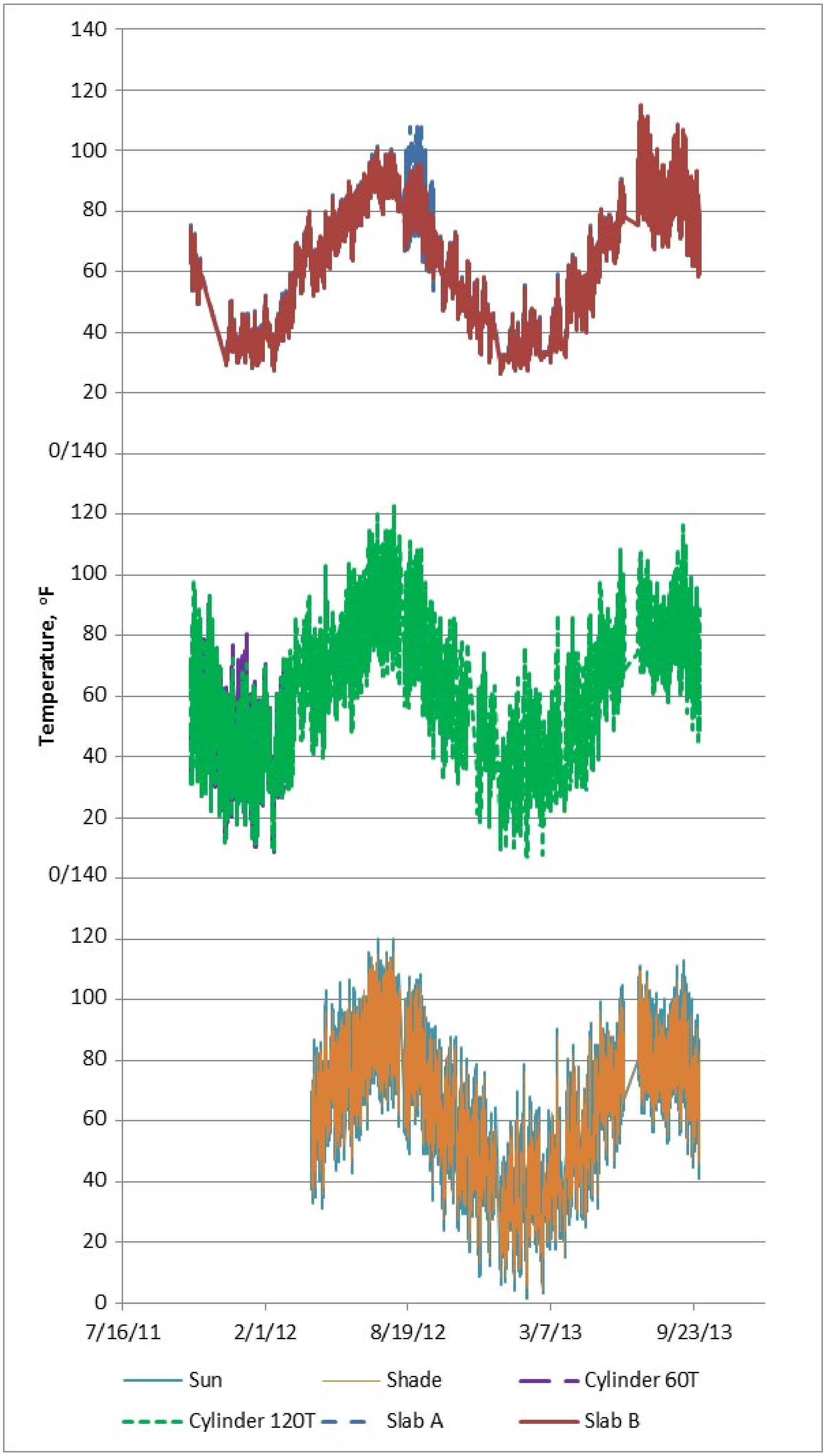

Figure A.2b: Temperature vs. time for fall slab with 100% portland cement (PC) mixture (different range).

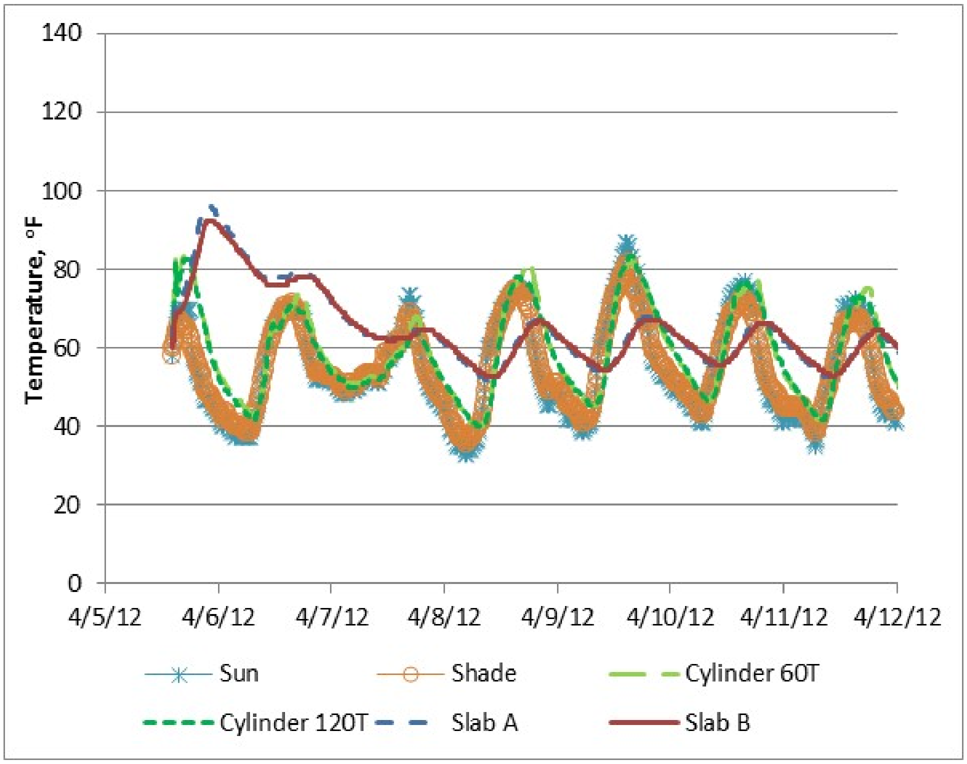

Figure A.3a: Temperature vs. time for spring slab with 100% portland cement (PC) mixture.

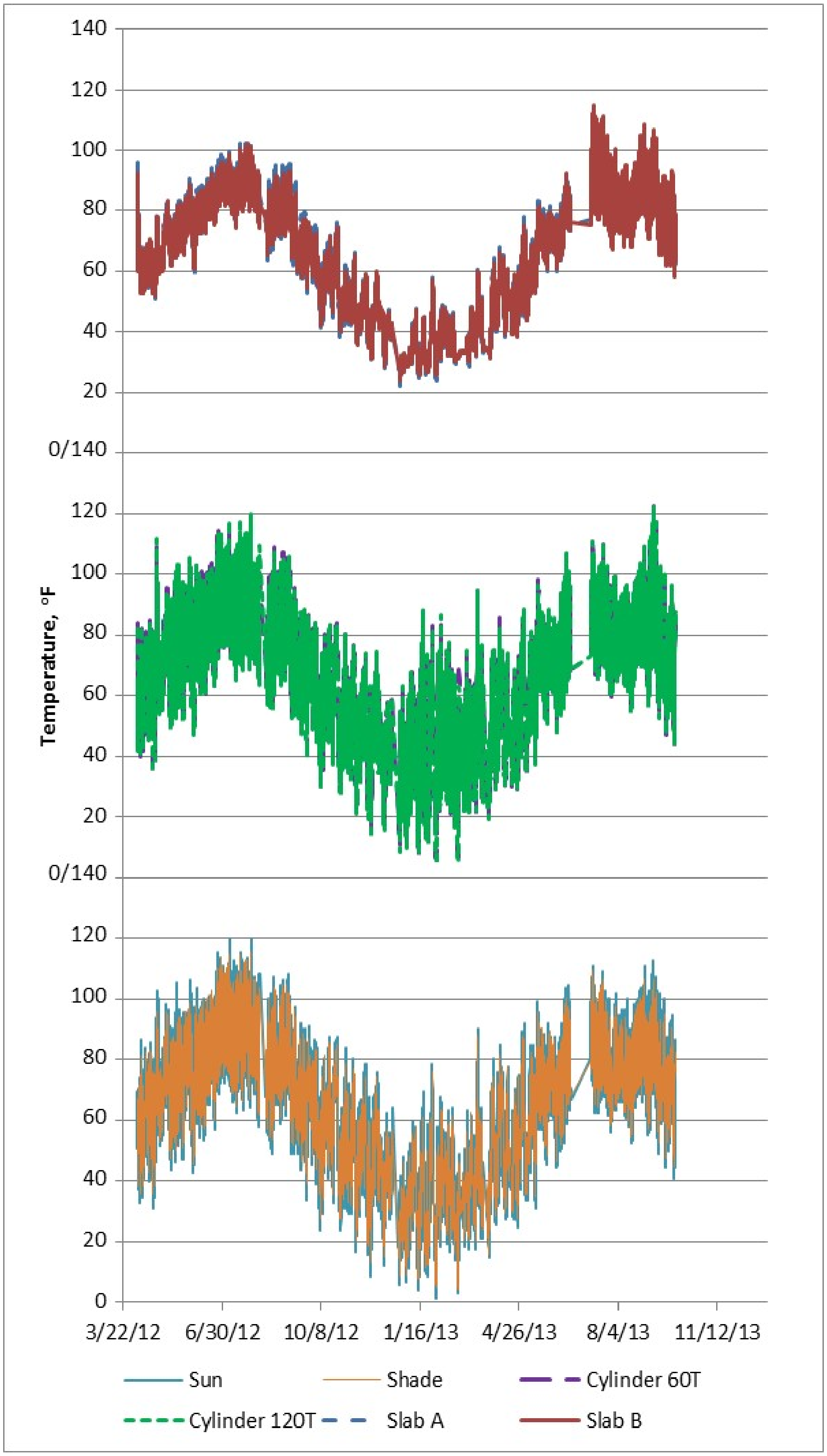

Figure A.3b: Temperature vs. time for spring slab with 100% portland cement (PC) mixture

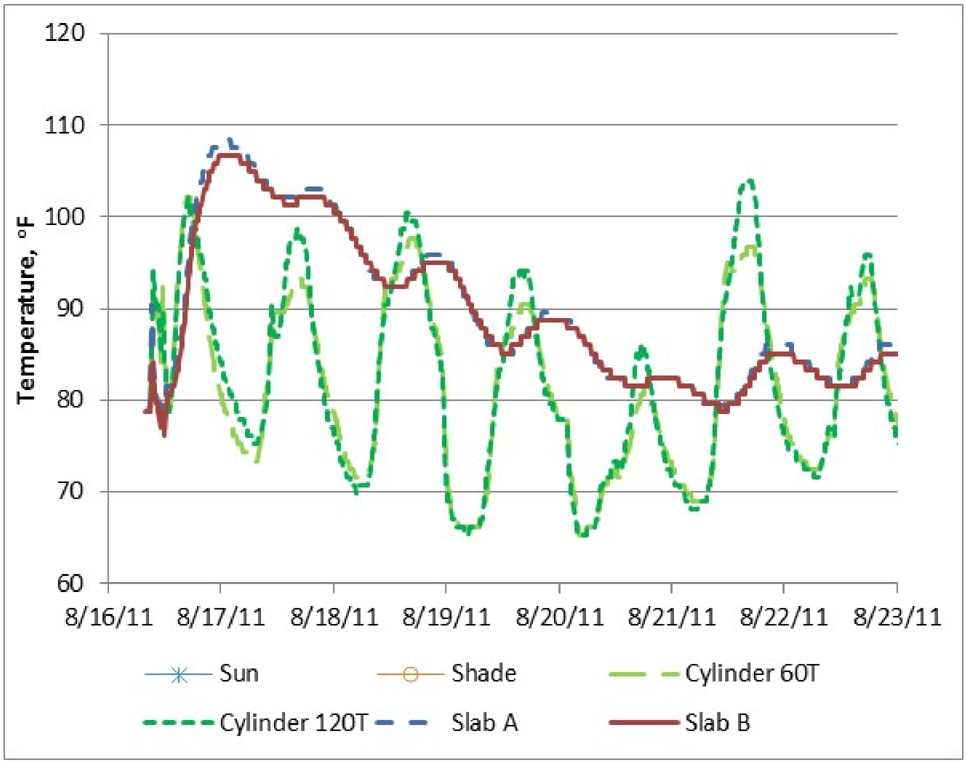

Figure A.4a: Temperature vs. time for summer slab with 65% portland cement/35% slag (PC/S/FA) mixture.

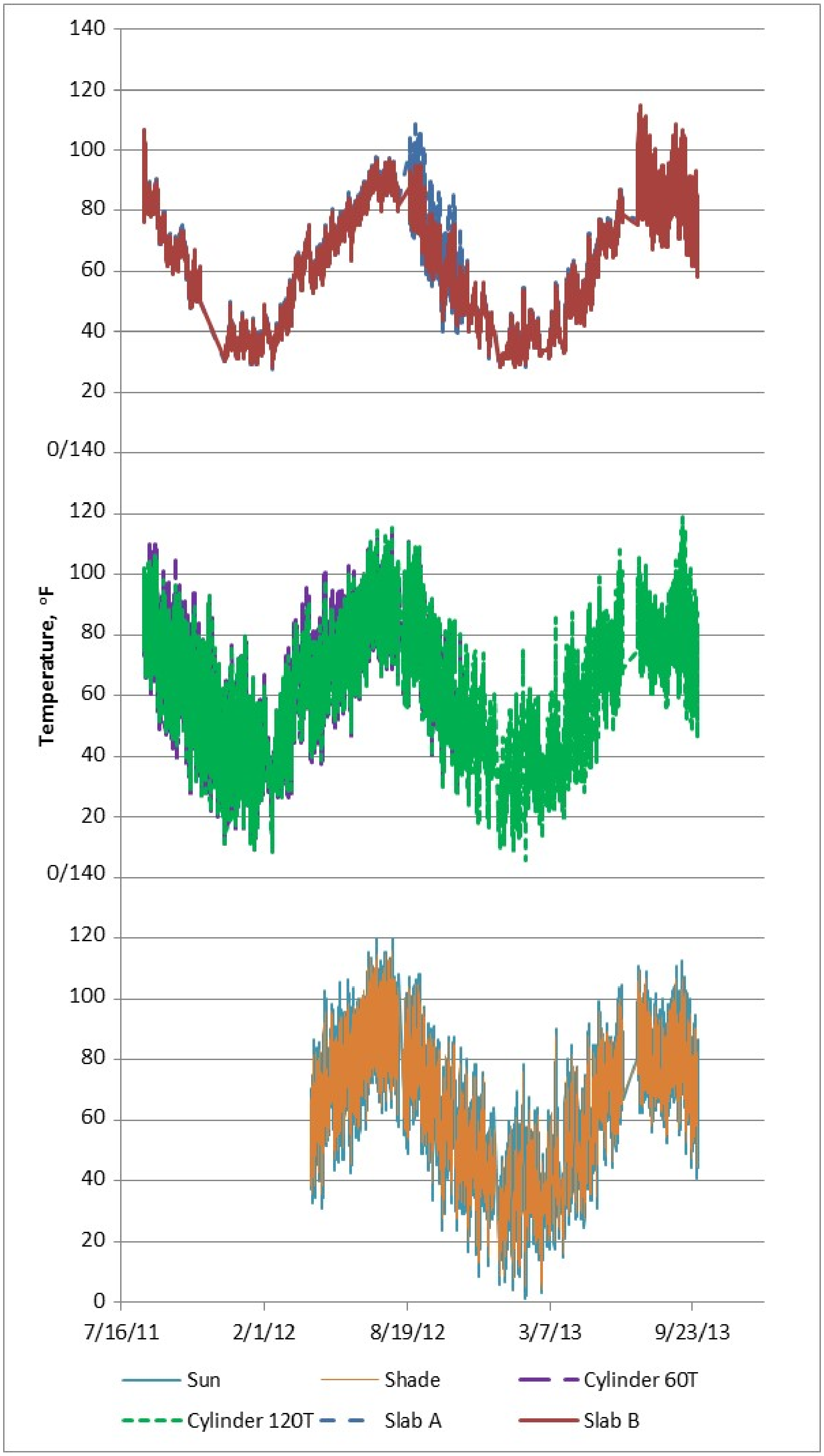

Figure A.4b: Temperature vs. time for summer slab with 65% portland cement/35% slag (PC/S/FA) mixture (different range).

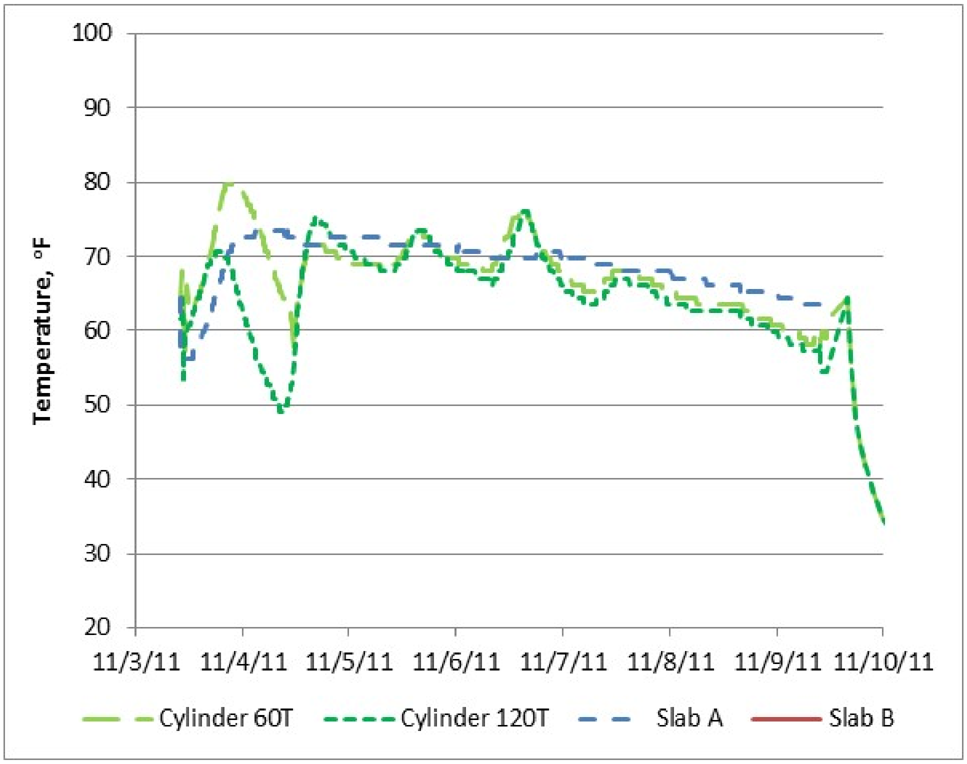

Figure A.5a: Temperature vs. time for fall slab with 65% portland cement/35% slag (PC/S/FA) mixture.

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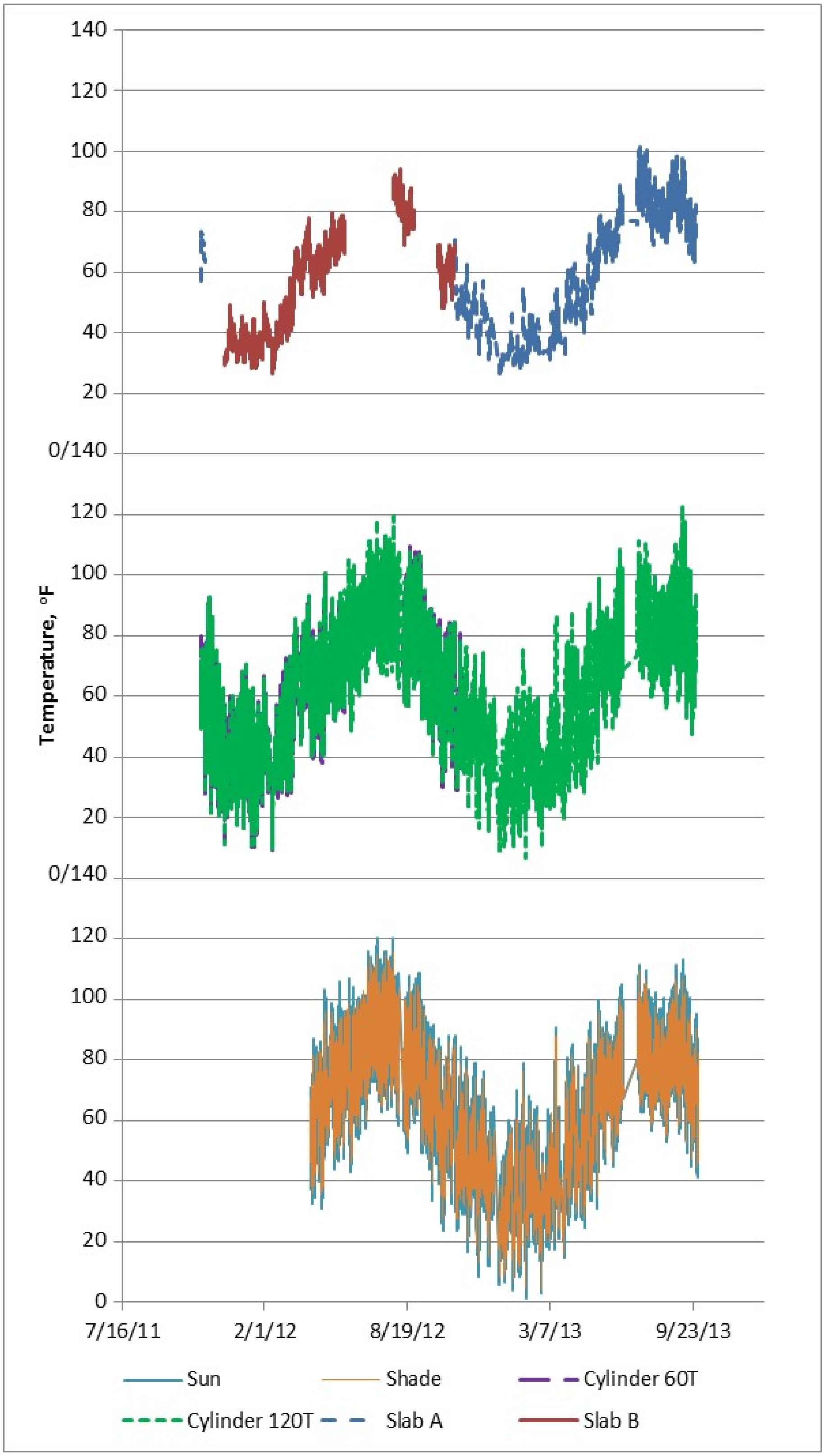

Figure A.5b: Temperature vs. time for fall slab with 65% portland cement/35% slag (PC/S/FA) mixture (different range).

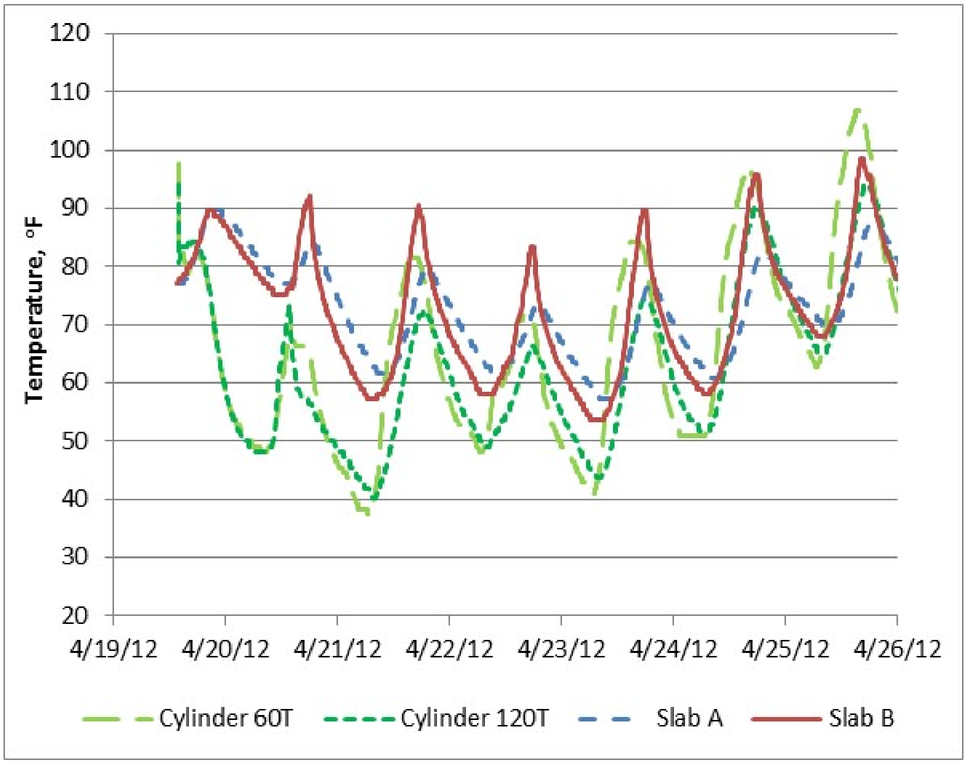

Figure A.6a: Temperature vs. time for spring slab with 65% portland cement/35% slag (PC/S/FA) mixture.

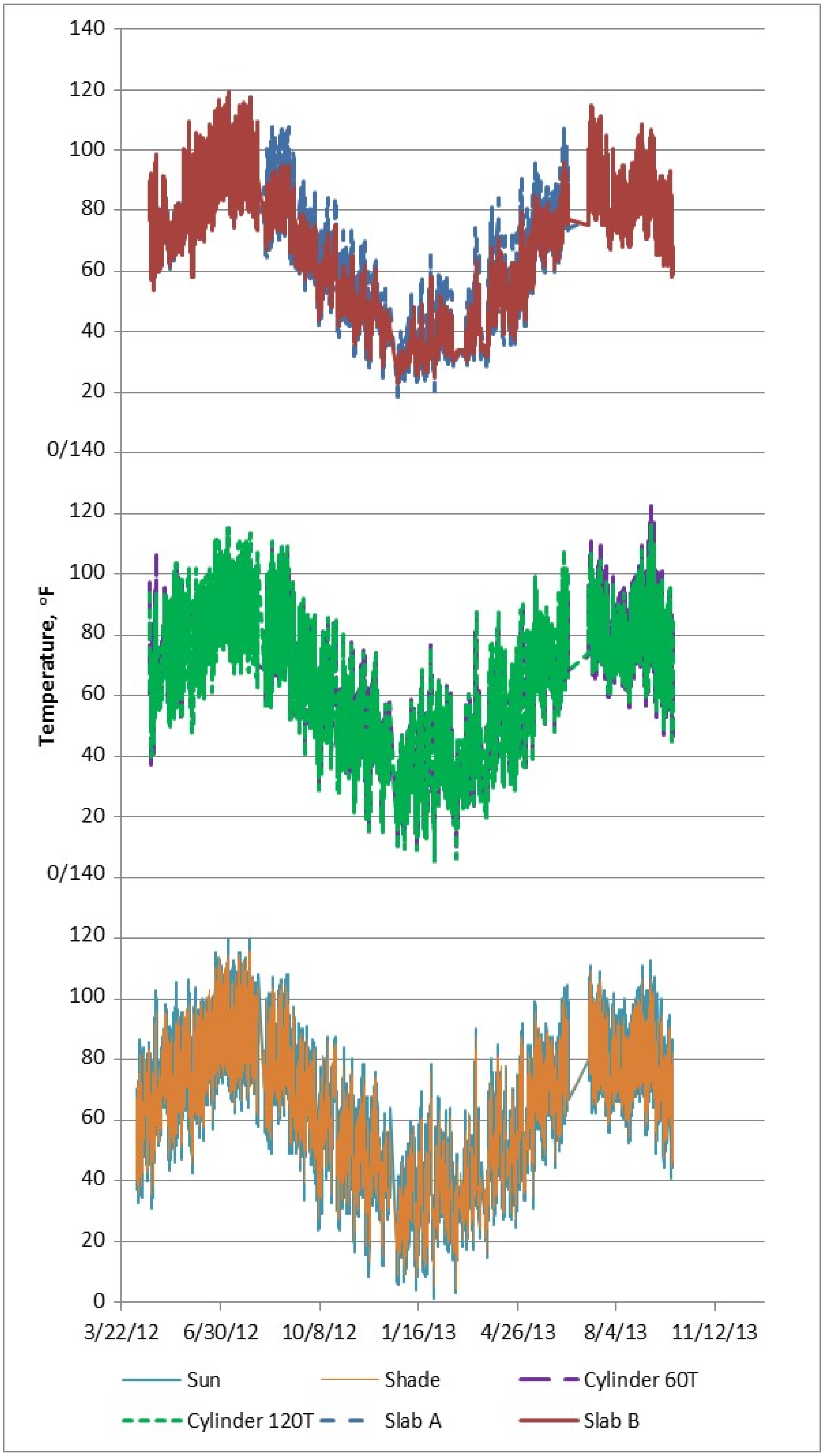

Figure A.6b: Temperature vs. time for spring slab with 65% portland cement/35% slag (PC/S/FA) mixture (different range).

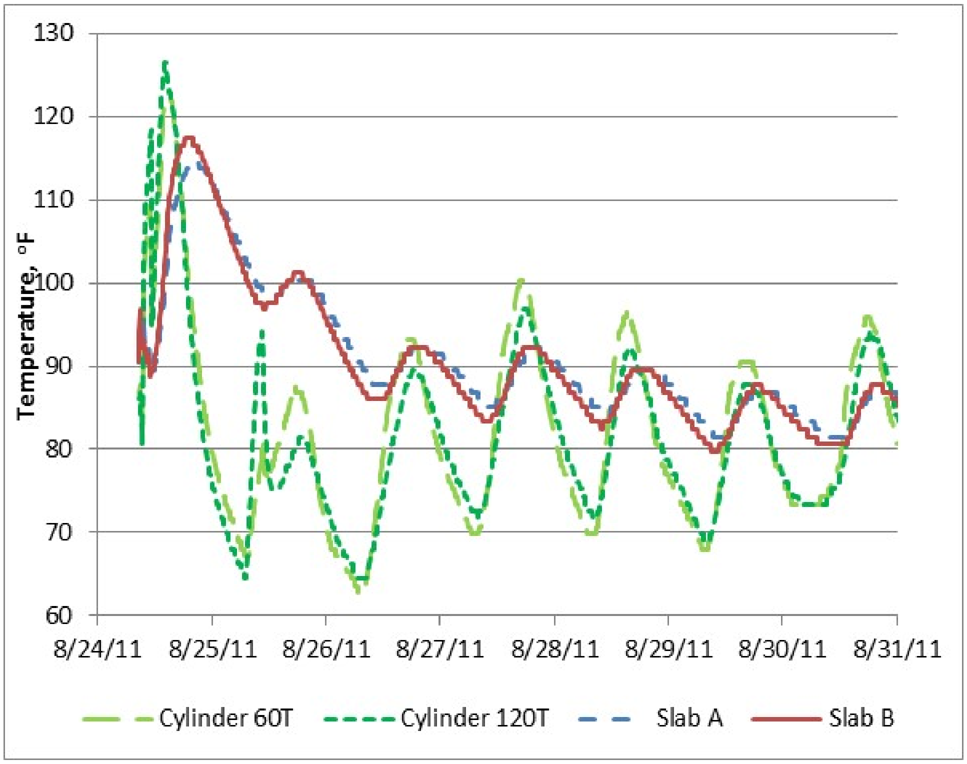

Figure A.7a: Temperature vs. time for summer slab with 60% portland cement/25% slag/15% Class C fly ash (PC/S/FA) mixture.

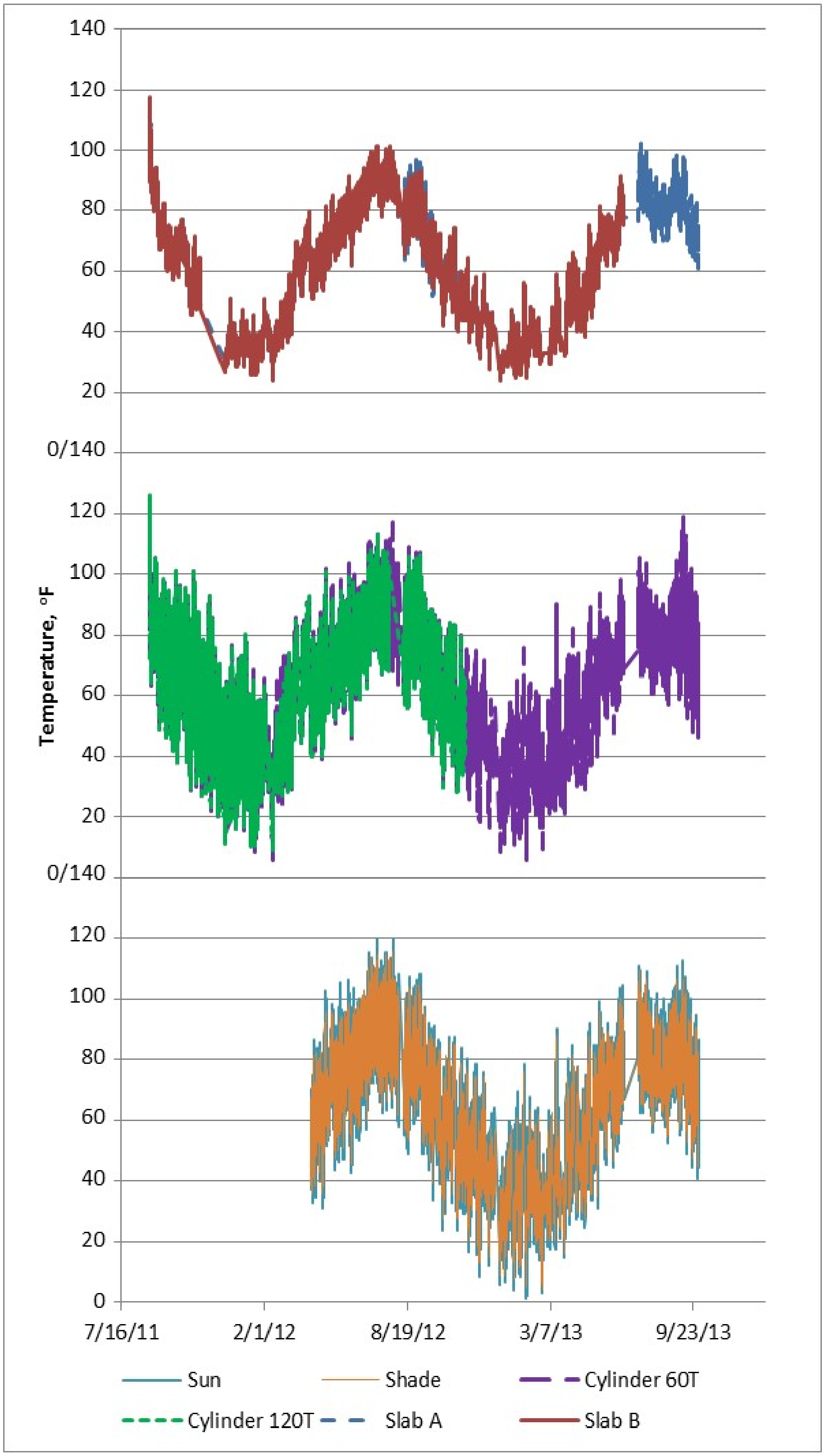

Figure A.7b: Temperature vs. time for summer slab with 60% portland cement/25% slag/15% Class C fly ash (PC/S/FA) mixture (different range).

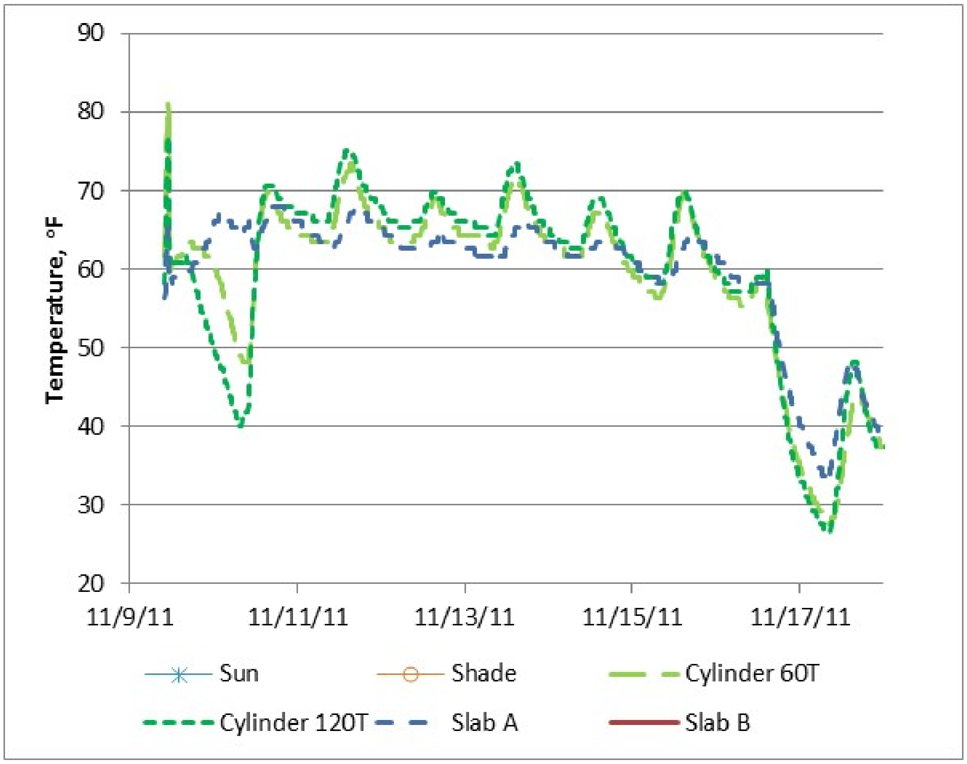

Figure A.8a: Temperature vs. time for fall slab with 60% portland cement/25% slag/15% Class C fly ash (PC/S/FA) mixture.

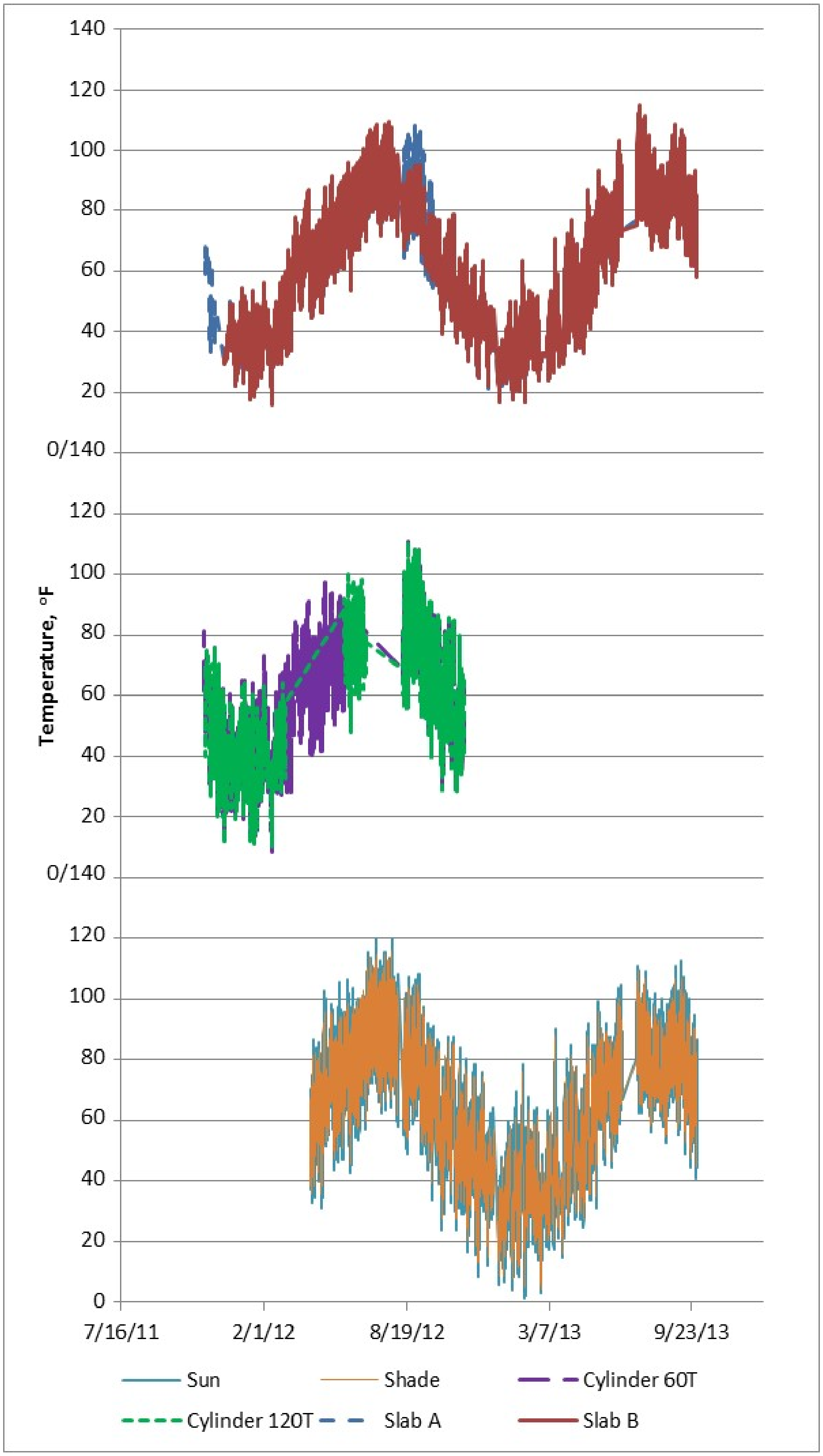

Figure A.8b: Temperature vs. time for fall slab with 60% portland cement/25% slag/15% Class C fly ash (PC/S/FA) mixture (different range).

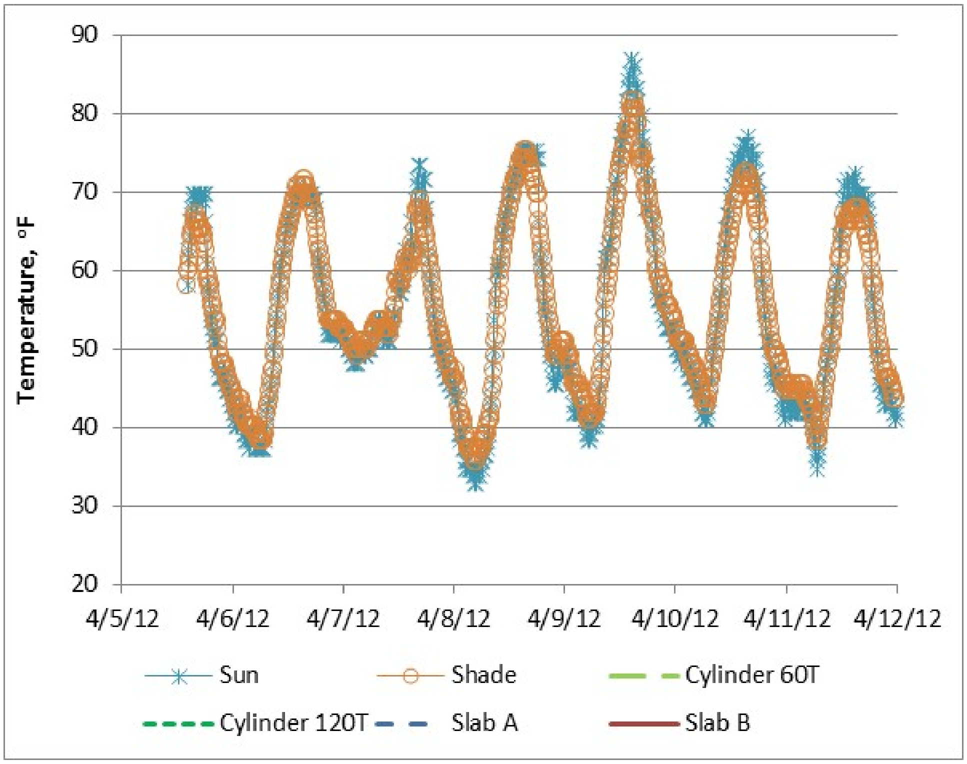

Figure A.9a: Temperature vs. time for spring slab with 60% portland cement/25% slag/15% Class C fly ash (PC/S/FA) mixture.

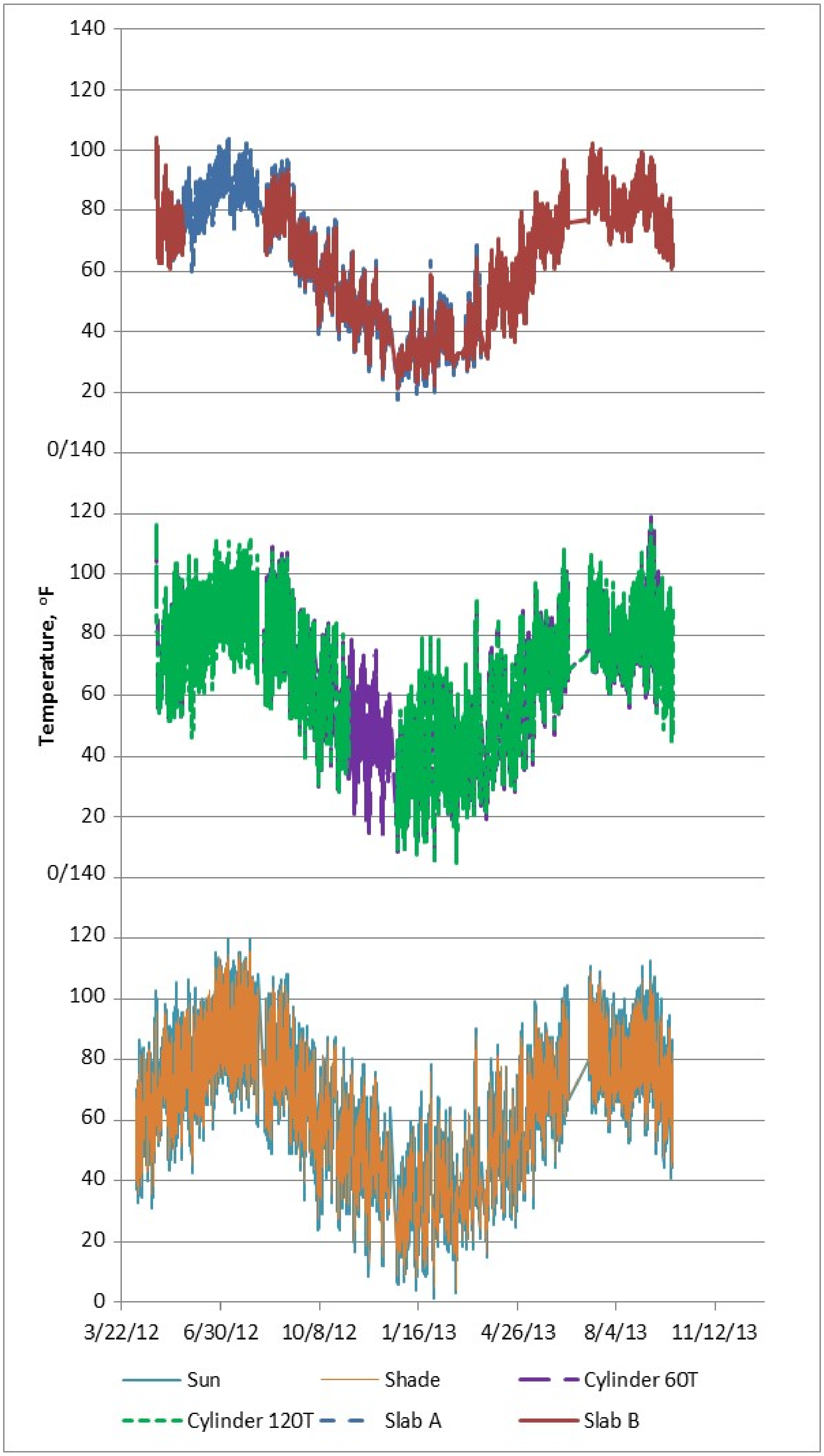

Figure A.9b: Temperature vs. time for spring slab with 60% portland cement/25% slag/15% Class C fly ash (PC/S/FA) mixture (different range).

APPENDIX B: STUDENT'S T-TEST COMPARISONS

Table B.1: Student's T-Test Results (*p* values) for 28-day Compressive Strengths

Summer Slab, 100% PC-28 day			Lab	Field	Core
	Avg.		**4490**	**4160**	**4300**
		Std. Dev	**208**	**371**	**325**
Lab	**4490**	**208**	1.000	0.250	0.435
Field	**4160**	**371**	0.250	1.000	0.656
Core	**4300**	**325**	0.435	0.656	1.000

Summer Slab, 65% PC/35% S-28 day			Lab	Field	Core
	Avg.		**5610**	**4630**	**4890**
		Std. Dev	**658**	**427**	**801**
Lab	**5610**	**658**	1.000	**0.097**	0.294
Field	**4630**	**427**	**0.097**	1.000	0.654
Core	**4890**	**801**	0.294	0.654	1.000

Summer Slab, 60% PC/25% S/15% FA-28 day			Lab	Field	Core
	Avg.		**5160**	**4070**	**5170**
		Std. Dev	**59**	**306**	**410**
Lab	**5160**	**59**	1.000	**0.004**	0.990
Field	**4070**	**306**	**0.004**	1.000	**0.021**
Core	**5170**	**410**	0.990	**0.021**	1.000

Fall Slab, 100% PC-28 day			Lab	Field	Core
	Avg.		**5230**	**4820**	**4730**
		Std. Dev	**95**	**580**	**485**
Lab	**5230**	**95**	1.000	0.294	0.155
Field	**4820**	**580**	0.294	1.000	0.847
Core	**4730**	**485**	0.155	0.847	1.000

Fall Slab, 65% PC/35% S-28 day			Lab	Field	Core
	Avg.		**5450**	**5690**	**5560**
		Std. Dev	**468**	**346**	**337**
Lab	**5450**	**468**	1.000	0.515	0.758
Field	**5690**	**346**	0.515	1.000	0.665
Core	**5560**	**337**	0.758	0.665	1.000

Fall Slab, 60% PC/25% S/15% FA-28 day			Lab	Field	Core
	Avg.		**4410**	**3490**	**4070**
		Std. Dev	**252**	**730**	**163**
Lab	**4410**	**252**	1.000	0.110	0.114
Field	**3490**	**730**	0.110	1.000	0.257
Core	**4070**	**163**	0.114	0.257	1.000

Spring Slab, 100% PC-28 day			Lab	Field	Core
	Avg.		**6780**	**6980**	**5760**
		Std. Dev	**658**	**427**	**801**
Lab	**6780**	**658**	1.000	0.539	**0.033**
Field	**6980**	**427**	0.539	1.000	**0.034**
Core	**5760**	**801**	**0.033**	**0.034**	1.000

Spring Slab, 65% PC/35% S-28 day			Lab	Field	Core
	Avg.		**6130**	**5270**	**5610**
		Std. Dev	**525**	**148**	**424**
Lab	**6130**	**525**	1.000	**0.053**	0.258
Field	**5270**	**148**	**0.053**	1.000	0.256
Core	**5610**	**424**	0.258	0.256	1.000

Spring Slab, 60% PC/25% S/15% FA-28 day			Lab	Field	Core
	Avg.		**5490**	**5120**	**5120**
		Std. Dev	**452**	**287**	**474**
Lab	**5490**	**452**	1.000	0.294	0.387
Field	**5120**	**287**	0.294	1.000	0.984
Core	**5120**	**474**	0.387	0.984	1.000

Table B.2: Student's T-Test Results (p values) for 56-day Compressive Strengths

Summer Slab, 100% PC-56 day			Lab	Field	Core
	Avg.		**5430**	**4780**	**4830**
		Std. Dev	**312**	**521**	**181**
Lab	**5430**	**312**	1.000	0.140	**0.045**
Field	**4780**	**521**	0.140	1.000	0.898
Core	**4830**	**181**	**0.045**	0.898	1.000

Summer Slab, 65% PC/35% S-56 day			Lab	Field	Core
	Avg.		**5780**	**4900**	**5990**
		Std. Dev	**390**	**492**	**182**
Lab	**5780**	**390**	1.000	**0.071**	0.445
Field	**4900**	**492**	**0.071**	1.000	**0.023**
Core	**5990**	**182**	0.445	**0.023**	1.000

Summer Slab, 60% PC/25% S/15% FA-56 day			Lab	Field	Core
	Avg.		**5200**	**4210**	**4940**
		Std. Dev	**234**	**511**	**809**
Lab	**5200**	**234**	1.000	**0.038**	0.621
Field	**4210**	**511**	**0.038**	1.000	0.259
Core	**4940**	**809**	0.621	0.259	1.000

Fall Slab, 100% PC-56 day			Lab	Field	Core
	Avg.		**5600**	**5370**	**5180**
		Std. Dev	**314**	**388**	**180**
Lab	**5600**	**314**	1.000	0.475	0.115
Field	**5370**	**388**	0.475	1.000	0.477
Core	**5180**	**180**	0.115	0.477	1.000

Fall Slab, 65% PC/35% S-56 day			Lab	Field	Core
	Avg.		**6360**	**5770**	**6030**
		Std. Dev	**241**	**540**	**820**
Lab	**6360**	**241**	1.000	0.163	0.544
Field	**5770**	**540**	0.163	1.000	0.674
Core	**6030**	**820**	0.544	0.674	1.000

Fall Slab, 60% PC/25% S/15% FA-56 day			Lab	Field	Core
	Avg.	**Std. Dev**	**5060**	**4320**	**4450**
			119	**596**	**336**
Lab	**5060**	**119**	1.000	**0.024**	**0.041**
Field	**4320**	**596**	**0.024**	1.000	0.663
Core	**4450**	**336**	**0.041**	0.663	1.000

Spring Slab, 100% PC-56 day			Lab	Field	Core
	Avg.	**Std. Dev**	**6860**	**6710**	**6440**
			390	**492**	**182**
Lab	**6860**	**390**	1.000	0.832	0.469
Field	**6710**	**492**	0.832	1.000	0.725
Core	**6440**	**182**	0.469	0.725	1.000

Spring Slab, 65% PC/35% S-56 day			Lab	Field	Core
	Avg.	**Std. Dev**	**6210**	**6000**	**5690**
			437	**526**	**305**
Lab	**6210**	**437**	1.000	0.623	0.166
Field	**6000**	**526**	0.623	1.000	0.427
Core	**5690**	**305**	0.166	0.427	1.000

Spring Slab, 60% PC/25% S/15% FA-56 day			Lab	Field	Core
	Avg.	**Std. Dev**	**5950**	**5260**	**5650**
			318	**251**	**560**
Lab	**5950**	**318**	1.000	**0.043**	0.474
Field	**5260**	**251**	**0.043**	1.000	0.333
Core	**5650**	**560**	0.474	0.333	1.000

Table B.3: Student's T-Test Results (*p* values) for 90-day Compressive Strengths

Summer Slab, 100% PC-90 day			Lab	Field	Core
	Avg.		**5420**	**4660**	**5300**
		Std. Dev	**269**	**359**	**415**
Lab	**5420**	**269**	1.000	**0.043**	0.704
Field	**4660**	**359**	**0.043**	1.000	0.114
Core	**5300**	**415**	0.704	0.114	1.000

Summer Slab, 65% PC/35% S-90 day			Lab	Field	Core
	Avg.		**6110**	**4240**	**5400**
		Std. Dev	**122**	**364**	**238**
Lab	**6110**	**122**	1.000	**0.001**	**0.010**
Field	**4240**	**364**	**0.001**	1.000	**0.010**
Core	**5400**	**238**	**0.010**	**0.010**	1.000

Summer Slab, 60% PC/25% S/15% FA-90 day			Lab	Field	Core
	Avg.		**5510**	**4690**	**4950**
		Std. Dev	**335**	**367**	**197**
Lab	**5510**	**335**	1.000	**0.046**	**0.067**
Field	**4690**	**367**	**0.046**	1.000	0.341
Core	**4950**	**197**	**0.067**	0.341	1.000

Fall Slab, 100% PC-90 day			Lab	Field	Core
	Avg.		**5530**	**5230**	**4660**
		Std. Dev	**654**	**118**	**457**
Lab	**5530**	**654**	1.000	0.478	0.130
Field	**5230**	**118**	0.478	1.000	0.102
Core	**4660**	**457**	0.130	0.102	1.000

Fall Slab, 65% PC/35% S-90 day			Lab	Field	Core
	Avg.		**6650**	**6040**	**6340**
		Std. Dev	**415**	**159**	**219**
Lab	**6650**	**415**	1.000	**0.078**	0.321
Field	**6040**	**159**	**0.078**	1.000	0.131
Core	**6340**	**219**	0.321	0.131	1.000

Fall Slab, 60% PC/25% S/15% FA-90 day			Lab	Field	Core
	Avg.		**5290**	**4110**	**4400**
		Std. Dev	**327**	**234**	**528**
Lab	**5290**	**327**	1.000	**0.007**	**0.068**
Field	**4110**	**234**	**0.007**	1.000	0.443
Core	**4400**	**528**	**0.068**	0.443	1.000

Spring Slab, 100% PC-90 day			Lab	Field	Core
	Avg.		**7170**	**7080**	**7130**
		Std. Dev	**122**	**364**	**238**
Lab	**7170**	**122**	1.000	0.676	0.917
Field	**7080**	**364**	0.676	1.000	0.925
Core	**7130**	**238**	0.917	0.925	1.000

Spring Slab, 65% PC/35% S-90 day			Lab	Field	Core
	Avg.		**6800**	**5770**	**5860**
		Std. Dev	**57**	**257**	**375**
Lab	**6800**	**57**	1.000	**0.003**	**0.013**
Field	**5770**	**257**	**0.003**	1.000	0.758
Core	**5860**	**375**	**0.013**	0.758	1.000

Spring Slab, 60% PC/25% S/15% FA-90 day			Lab	Field	Core
	Avg.		**6330**	**5850**	**6000**
		Std. Dev	**712**	**483**	**711**
Lab	**6330**	**712**	1.000	0.386	0.593
Field	**5850**	**483**	0.386	1.000	0.782
Core	**6000**	**711**	0.593	0.782	1.000

Table B.4: Student's T-Test Results (*p* values) for 180-day Compressive Strengths

Summer Slab, 100% PC-180 day			Lab	Field	Core
	Avg.		**5220**	**3900**	**4130**
		Std. Dev	**325**	**445**	**610**
Lab	**5220**	**325**	1.000	**0.014**	**0.052**
Field	**3900**	**445**	**0.014**	1.000	0.626
Core	**4130**	**610**	**0.052**	0.626	1.000

Summer Slab, 65% PC/35% S-180 day			Lab	Field	Core
	Avg.		**6150**	**4380**	**5290**
		Std. Dev	**622**	**464**	**239**
Lab	**6150**	**622**	1.000	**0.017**	**0.088**
Field	**4380**	**464**	**0.017**	1.000	**0.040**
Core	**5290**	**239**	**0.088**	**0.040**	1.000

Summer Slab, 60% PC/25% S/15% FA-180 day			Lab	Field	Core
	Avg.		**5760**	**4650**	**4790**
		Std. Dev	**111**	**510**	**450**
Lab	**5760**	**111**	1.000	**0.022**	**0.023**
Field	**4650**	**510**	**0.022**	1.000	0.739
Core	**4790**	**450**	**0.023**	0.739	1.000

Fall Slab, 100% PC-180 day			Lab	Field	Core
	Avg.		**6130**	**6120**	**5820**
		Std. Dev	**456**	**46**	**983**
Lab	**6130**	**456**	1.000	0.972	0.650
Field	**6120**	**46**	0.972	1.000	0.629
Core	**5820**	**983**	0.650	0.629	1.000

Fall Slab, 65% PC/35% S-180 day			Lab	Field	Core
	Avg.		**7340**	**6780**	**6600**
		Std. Dev	**40**	**347**	**596**
Lab	**7340**	**40**	1.000	**0.051**	0.100
Field	**6780**	**347**	**0.051**	1.000	0.675
Core	**6600**	**596**	0.100	0.675	1.000

Fall Slab, 60% PC/25% S/15% FA-180 day			Lab	Field	Core
	Avg.		**5010**	**4690**	**5150**
		Std. Dev	**350**	**426**	**566**
Lab	**5010**	**350**	1.000	0.376	0.728
Field	**4690**	**426**	0.376	1.000	0.323
Core	**5150**	**566**	0.728	0.323	1.000

Spring Slab, 100% PC-180 day			Lab	Field	Core
	Avg.		**7360**	**6690**	**7340**
		Std. Dev	**622**	**464**	**239**
Lab	**7360**	**622**	1.000	0.575	0.986
Field	**6690**	**464**	0.575	1.000	**0.013**
Core	**7340**	**239**	0.986	**0.013**	1.000

Spring Slab, 65% PC/35% S-180 day			Lab	Field	Core
	Avg.		**7400**	**6010**	**6510**
		Std. Dev	**46**	**262**	**206**
Lab	**7400**	**46**	1.000	**0.001**	**0.002**
Field	**6010**	**262**	**0.001**	1.000	**0.061**
Core	**6510**	**206**	**0.002**	**0.061**	1.000

Spring Slab, 60% PC/25% S/15% FA-180 day			Lab	Field	Core
	Avg.		**6620**	**5630**	**5940**
		Std. Dev	**471**	**307**	**767**
Lab	**6620**	**471**	1.000	**0.038**	0.259
Field	**5630**	**307**	**0.038**	1.000	0.555
Core	**5940**	**767**	0.259	0.555	1.000

Table B.5: Student's T-Test Results (*p* values) for 360-day Compressive Strengths

Summer Slab, 100% PC-360 day			Lab	Field	Core
	Avg.		**5900**	**5410**	**4940**
		Std. Dev	**44**	**630**	**436**
Lab	**5900**	**44**	1.000	0.250	**0.019**
Field	**5410**	**630**	0.250	1.000	0.348
Core	**4940**	**436**	**0.019**	0.348	1.000

Summer Slab, 65% PC/35% S-360 day			Lab	Field	Core
	Avg.		**6750**	**6310**	**6450**
		Std. Dev	**292**	**429**	**370**
Lab	**6750**	**292**	1.000	0.213	0.332
Field	**6310**	**429**	0.213	1.000	0.684
Core	**6450**	**370**	0.332	0.684	1.000

Summer Slab, 60% PC/25% S/15% FA-360 day			Lab	Field	Core
	Avg.		**6750**	**5640**	**6370**
		Std. Dev	**284**	**719**	**359**
Lab	**6750**	**284**	1.000	**0.068**	0.224
Field	**5640**	**719**	**0.068**	1.000	0.192
Core	**6370**	**359**	0.224	0.192	1.000

Fall Slab, 100% PC-360 day			Lab	Field	Core
	Avg.		**6580**	**5870**	**5640**
		Std. Dev	**410**	**499**	**275**
Lab	**6580**	**410**	1.000	0.128	**0.030**
Field	**5870**	**499**	0.128	1.000	0.528
Core	**5640**	**275**	**0.030**	0.528	1.000

Fall Slab, 65% PC/35% S-360 day			Lab	Field	Core
	Avg.		**6780**	**6630**	**7320**
		Std. Dev	**130**	**480**	**846**
Lab	**6780**	**130**	1.000	0.636	0.338
Field	**6630**	**480**	0.636	1.000	0.290
Core	**7320**	**846**	0.338	0.290	1.000

Fall Slab, 60% PC/25% S/15% FA-360 day			Lab	Field	Core
	Avg.		**4750**	**5390**	**5570**
		Std. Dev	**344**	**70**	**243**
Lab	**4750**	**344**	1.000	**0.035**	**0.028**
Field	**5390**	**70**	**0.035**	1.000	0.285
Core	**5570**	**243**	**0.028**	0.285	1.000

Spring Slab, 100% PC-360 day			Lab	Field	Core
	Avg.		**7860**	**6870**	**8030**
		Std. Dev	**292**	**429**	**370**
Lab	**7860**	**292**	1.000	0.128	0.677
Field	**6870**	**429**	0.128	1.000	**0.031**
Core	**8030**	**370**	0.677	**0.031**	1.000

Spring Slab, 65% PC/35% S-360 day			Lab	Field	Core
	Avg.		**7100**	**6130**	**7470**
		Std. Dev	**677**	**614**	**173**
Lab	**7100**	**677**	1.000	0.140	0.407
Field	**6130**	**614**	0.140	1.000	**0.022**
Core	**7470**	**173**	0.407	**0.022**	1.000

Spring Slab, 60% PC/25% S/15% FA-360 day			Lab	Field	Core
	Avg.		**6390**	**6000**	**6300**
		Std. Dev	**715**	**288**	**208**
Lab	**6390**	**715**	1.000	0.431	0.850
Field	**6000**	**288**	0.431	1.000	0.213
Core	**6300**	**208**	0.850	0.213	1.000

Table B.6: Student's T-Test Results (*p* values) for 720-day Compressive Strengths

Summer Slab, 100% PC-720 day			Lab	Field	Core
	Avg.		**5730**	**5010**	**5120**
		Std. Dev	**423**	**571**	**125**
Lab	**5730**	**423**	1.000	0.156	**0.075**
Field	**5010**	**571**	0.156	1.000	0.768
Core	**5120**	**125**	**0.075**	0.768	1.000

Summer Slab, 65% PC/35% S-720 day			Lab	Field	Core
	Avg.		**6610**	**5690**	**5810**
		Std. Dev	**374**	**417**	**60**
Lab	**6610**	**374**	1.000	0.046	**0.022**
Field	**5690**	**417**	0.046	1.000	0.639
Core	**5810**	**60**	**0.022**	0.639	1.000

Summer Slab, 60% PC/25% S/15% FA-720 day			Lab	Field	Core
	Avg.		**6580**	**5680**	**6120**
		Std. Dev	**312**	**549**	**717**
Lab	**6580**	**312**	1.000	**0.070**	0.363
Field	**5680**	**549**	**0.070**	1.000	0.453
Core	**6120**	**717**	0.363	0.453	1.000

Fall Slab, 100% PC-720 day			Lab	Field	Core
	Avg.		**6340**	**7010**	**6140**
		Std. Dev	**360**	**302**	**25**
Lab	**6340**	**360**	1.000	**0.067**	0.392
Field	**7010**	**302**	**0.067**	1.000	**0.007**
Core	**6140**	**25**	0.392	**0.007**	1.000

Fall Slab, 65% PC/35% S-720 day			Lab	Field	Core
	Avg.		**6280**	**6250**	**7960**
		Std. Dev	**676**	**658**	**1140**
Lab	**6280**	**676**	1.000	0.963	**0.093**
Field	**6250**	**658**	0.963	1.000	0.088
Core	**7960**	**1140**	**0.093**	0.088	1.000

Fall Slab, 60% PC/25% S/15% FA-720 day			Lab	Field	Core
	Avg.		**6130**	**5710**	**6210**
		Std. Dev	**378**	**711**	**141**
Lab	**6130**	**378**	1.000	0.425	0.739
Field	**5710**	**711**	0.425	1.000	0.301
Core	**6210**	**141**	0.739	0.301	1.000

Spring Slab, 100% PC-720 day			Lab	Field	Core
	Avg.		**7560**	**5850**	**5950**
		Std. Dev	**374**	**417**	**60**
Lab	**7560**	**374**	1.000	0.812	0.664
Field	**5850**	**417**	0.812	1.000	0.800
Core	**5950**	**60**	0.664	0.800	1.000

Spring Slab, 65% PC/35% S-720 day			Lab	Field	Core
	Avg.		**7240**	**6270**	**6270**
		Std. Dev	**735**	**401**	**380**
Lab	**7240**	**735**	1.000	0.116	0.113
Field	**6270**	**401**	0.116	1.000	1.000
Core	**6270**	**380**	0.113	1.000	1.000

Spring Slab, 60% PC/25% S/15% FA-720 day			Lab	Field	Core
	Avg.		**7370**	**7460**	**6690**
		Std. Dev	**487**	**229**	**928**
Lab	**7370**	**487**	1.000	0.794	0.320
Field	**7460**	**229**	0.794	1.000	0.234
Core	**6690**	**928**	0.320	0.234	1.000

Table B.7: Student's T-Test Results (*p* values) for 28-day Boil Test

Summer Slab, 100% PC-28 day			Lab	Field	Core
	Avg.		**0.125**	**0.136**	**0.127**
		Std. Dev	**0.0026**	**0.0111**	**0.0034**
Lab	**0.125**	**0.0026**	1.000	0.164	0.448
Field	**0.136**	**0.0111**	0.164	1.000	0.244
Core	**0.127**	**0.0034**	0.448	0.244	1.000

Summer Slab, 65% PC/35% S-28 day			Lab	Field	Core
	Avg.		**0.122**	**0.132**	**0.133**
		Std. Dev	**0.0013**	**0.0029**	**0.0064**
Lab	**0.122**	**0.0013**	1.000	**0.006**	**0.049**
Field	**0.132**	**0.0029**	**0.006**	1.000	0.863
Core	**0.133**	**0.0064**	**0.049**	0.863	1.000

Summer Slab, 60% PC/25% S/15% FA-28 day			Lab	Field	Core
	Avg.		**0.129**	**0.146**	**0.136**
		Std. Dev	**0.0036**	**0.0033**	**0.0056**
Lab	**0.129**	**0.0036**	1.000	**0.004**	0.165
Field	**0.146**	**0.0033**	**0.004**	1.000	**0.057**
Core	**0.136**	**0.0056**	0.165	**0.057**	1.000

Fall Slab, 100% PC-28 day			Lab	Field	Core
	Avg.		**0.124**	**0.132**	**0.130**
		Std. Dev	**0.0025**	**0.0029**	**0.0018**
Lab	**0.124**	**0.0025**	1.000	**0.012**	0.213
Field	**0.132**	**0.0029**	**0.012**	1.000	0.667
Core	**0.130**	**0.0018**	0.213	0.667	1.000

Fall Slab, 65% PC/35% S-28 day			Lab	Field	Core
	Avg.		**0.118**	**0.130**	**0.123**
		Std. Dev	**0.0040**	**0.0069**	**0.0018**
Lab	**0.118**	**0.0040**	1.000	**0.006**	**0.027**
Field	**0.130**	**0.0069**	**0.006**	1.000	**0.018**
Core	**0.123**	**0.0018**	**0.027**	**0.018**	1.000

Fall Slab, 60% PC/25% S/15% FA-28 day			Lab	Field	Core
	Avg.		**0.146**	**0.173**	**0.153**
		Std. Dev	**0.0013**	**0.0025**	**0.0244**
Lab	**0.146**	**0.0013**	1.000	**0.002**	0.132
Field	**0.173**	**0.0025**	**0.002**	1.000	**0.017**
Core	**0.153**	**0.0244**	0.132	**0.017**	1.000

Spring Slab, 100% PC-28 day			Lab	Field	Core
	Avg.		**0.111**	**0.122**	**0.115**
		Std. Dev	**0.0010**	**0.0065**	**0.0037**
Lab	**0.111**	**0.0010**	1.000	**0.039**	0.118
Field	**0.122**	**0.0065**	**0.039**	1.000	0.179
Core	**0.115**	**0.0037**	0.118	0.179	1.000

Spring Slab, 65% PC/35% S-28 day			Lab	Field	Core
	Avg.		**0.116**	**0.133**	**0.128**
		Std. Dev	**0.0033**	**0.0037**	**0.0015**
Lab	**0.116**	**0.0033**	1.000	**0.004**	**0.005**
Field	**0.133**	**0.0037**	**0.004**	1.000	**0.090**
Core	**0.128**	**0.0015**	**0.005**	**0.090**	1.000

Spring Slab, 60% PC/25% S/15% FA-28 day			Lab	Field	Core
	Avg.		**0.114**	**0.127**	**0.119**
		Std. Dev	**0.0013**	**0.0040**	**0.0022**
Lab	**0.114**	**0.0013**	1.000	**0.006**	**0.022**
Field	**0.127**	**0.0040**	**0.006**	1.000	**0.046**
Core	**0.119**	**0.0022**	**0.022**	**0.046**	1.000

Table B.8: Student's T-Test Results (*p* values) for 56-day Boil Test

Summer Slab, 100% PC-56 day			Lab	Field	Core
	Avg.		**0.127**	**0.141**	**0.133**
		Std. Dev	**0.0033**	**0.0046**	**0.0030**
Lab	**0.127**	**0.0033**	1.000	**0.015**	0.103
Field	**0.141**	**0.0046**	**0.015**	1.000	**0.063**
Core	**0.133**	**0.0030**	0.103	**0.063**	1.000

Summer Slab, 65% PC/35% S-56 day			Lab	Field	Core
	Avg.		**0.123**	**0.139**	**0.139**
		Std. Dev	**0.0029**	**0.0032**	**0.0155**
Lab	**0.123**	**0.0029**	1.000	**0.003**	0.167
Field	**0.139**	**0.0032**	**0.003**	1.000	0.934
Core	**0.139**	**0.0155**	0.167	0.934	1.000

Summer Slab, 60% PC/25% S/15% FA-56 day			Lab	Field	Core
	Avg.		**0.128**	**0.152**	**0.139**
		Std. Dev	**0.0037**	**0.0034**	**0.0072**
Lab	**0.128**	**0.0037**	1.000	**0.001**	**0.099**
Field	**0.152**	**0.0034**	**0.001**	1.000	**0.042**
Core	**0.139**	**0.0072**	**0.099**	**0.042**	1.000

Fall Slab, 100% PC-56 day			Lab	Field	Core
	Avg.		**0.119**	**0.129**	**0.120**
		Std. Dev	**0.0038**	**0.0054**	**0.0159**
Lab	**0.119**	**0.0038**	1.000	**0.011**	0.471
Field	**0.129**	**0.0054**	**0.011**	1.000	**0.018**
Core	**0.120**	**0.0159**	0.471	**0.018**	1.000

Fall Slab, 65% PC/35% S-56 day			Lab	Field	Core
	Avg.		**0.116**	**0.131**	**0.128**
		Std. Dev	**0.0069**	**0.0022**	**0.0029**
Lab	**0.116**	**0.0069**	1.000	**0.002**	**0.005**
Field	**0.131**	**0.0022**	**0.002**	1.000	0.258
Core	**0.128**	**0.0029**	**0.005**	0.258	1.000

Fall Slab, 60% PC/25% S/15% FA-56 day			Lab	Field	Core
	Avg.		**0.140**	**0.159**	**0.147**
		Std. Dev	**0.0009**	**0.0058**	**0.0040**
Lab	**0.140**	**0.0009**	1.000	**0.004**	0.147
Field	**0.159**	**0.0058**	**0.004**	1.000	**0.012**
Core	**0.147**	**0.0040**	0.147	**0.012**	1.000

Spring Slab, 100% PC-56 day			Lab	Field	Core
	Avg.		**0.103**	**0.107**	**0.104**
		Std. Dev	**0.0018**	**0.0010**	**0.0009**
Lab	**0.103**	**0.0018**	1.000	**0.022**	0.377
Field	**0.107**	**0.0010**	**0.022**	1.000	**0.014**
Core	**0.104**	**0.0009**	0.377	**0.014**	1.000

Spring Slab, 65% PC/35% S-56 day			Lab	Field	Core
	Avg.		**0.116**	**0.132**	**0.130**
		Std. Dev	**0.0018**	**0.0045**	**0.0059**
Lab	**0.116**	**0.0018**	1.000	**0.004**	**0.016**
Field	**0.132**	**0.0045**	**0.004**	1.000	0.617
Core	**0.130**	**0.0059**	**0.016**	0.617	1.000

Spring Slab, 60% PC/25% S/15% FA-56 day			Lab	Field	Core
	Avg.		**0.115**	**0.126**	**0.119**
		Std. Dev	**0.0032**	**0.0018**	**0.0038**
Lab	**0.115**	**0.0032**	1.000	**0.007**	0.241
Field	**0.126**	**0.0018**	**0.007**	1.000	**0.047**
Core	**0.119**	**0.0038**	0.241	**0.047**	1.000

Table B.9: Student's T-Test Results (*p* values) for 90-day Boil Test

Summer Slab, 100% PC-90 day			Lab	Field	Core
	Avg.		**0.124**	**0.144**	**0.132**
		Std. Dev	**0.0048**	**0.0060**	**0.0059**
Lab	**0.124**	**0.0048**	1.000	**0.012**	0.142
Field	**0.144**	**0.0060**	**0.012**	1.000	**0.077**
Core	**0.132**	**0.0059**	0.142	**0.077**	1.000

Summer Slab, 65% PC/35% S-90 day			Lab	Field	Core
	Avg.		**0.118**	**0.132**	**0.130**
		Std. Dev	**0.0006**	**0.0042**	**0.0014**
Lab	**0.118**	**0.0006**	1.000	**0.004**	**0.000**
Field	**0.132**	**0.0042**	**0.004**	1.000	0.529
Core	**0.130**	**0.0014**	**0.000**	0.529	1.000

Summer Slab, 60% PC/25% S/15% FA-90 day			Lab	Field	Core
	Avg.		**0.126**	**0.145**	**0.135**
		Std. Dev	**0.0017**	**0.0024**	**0.0086**
Lab	**0.126**	**0.0017**	1.000	**0.000**	0.170
Field	**0.145**	**0.0024**	**0.000**	1.000	0.132
Core	**0.135**	**0.0086**	0.170	0.132	1.000

Fall Slab, 100% PC-90 day			Lab	Field	Core
	Avg.		**0.119**	**0.126**	**0.126**
		Std. Dev	**0.0042**	**0.0022**	**0.0017**
Lab	**0.119**	**0.0042**	1.000	**0.036**	**0.026**
Field	**0.126**	**0.0022**	**0.036**	1.000	0.753
Core	**0.126**	**0.0017**	**0.026**	0.753	1.000

Fall Slab, 65% PC/35% S-90 day			Lab	Field	Core
	Avg.		**0.120**	**0.127**	**0.124**
		Std. Dev	**0.0053**	**0.0038**	**0.0030**
Lab	**0.120**	**0.0053**	1.000	0.184	0.157
Field	**0.127**	**0.0038**	0.184	1.000	0.506
Core	**0.124**	**0.0030**	0.157	0.506	1.000

Fall Slab, 60% PC/25% S/15% FA-90 day			Lab	Field	Core
	Avg.		**0.141**	**0.167**	**0.144**
		Std. Dev	**0.0020**	**0.0029**	**0.0050**
Lab	**0.141**	**0.0020**	1.000	**0.000**	0.792
Field	**0.167**	**0.0029**	**0.000**	1.000	0.190
Core	**0.144**	**0.0050**	0.792	0.190	1.000

Spring Slab, 100% PC-90 day			Lab	Field	Core
	Avg.		**0.101**	**0.110**	**0.102**
		Std. Dev	**0.0035**	**0.0053**	**0.0017**
Lab	**0.101**	**0.0035**	1.000	**0.070**	0.568
Field	**0.110**	**0.0053**	**0.070**	1.000	**0.077**
Core	**0.102**	**0.0017**	0.568	**0.077**	1.000

Spring Slab, 65% PC/35% S-90 day			Lab	Field	Core
	Avg.		**0.110**	**0.126**	**0.131**
		Std. Dev	**0.0014**	**0.0067**	**0.0079**
Lab	**0.110**	**0.0014**	1.000	**0.015**	**0.011**
Field	**0.126**	**0.0067**	**0.015**	1.000	0.471
Core	**0.131**	**0.0079**	**0.011**	0.471	1.000

Spring Slab, 60% PC/25% S/15% FA-90 day			Lab	Field	Core
	Avg.		**0.115**	**0.132**	**0.126**
		Std. Dev	**0.0040**	**0.0025**	**0.0072**
Lab	**0.115**	**0.0040**	1.000	**0.003**	**0.071**
Field	**0.132**	**0.0025**	**0.003**	1.000	0.252
Core	**0.126**	**0.0072**	**0.071**	0.252	1.000

Table B.10: Student's T-Test Results (*p* values) for 180-day Boil Test

Summer Slab, 100% PC-180 day			Lab	Field	Core
	Avg.		**0.117**	**0.139**	**0.115**
		Std. Dev	**0.0109**	**0.0018**	**0.0046**
Lab	**0.117**	**0.0109**	1.000	**0.029**	0.766
Field	**0.139**	**0.0018**	**0.029**	1.000	**0.001**
Core	**0.115**	**0.0046**	0.766	**0.001**	1.000

Summer Slab, 65% PC/35% S-180 day			Lab	Field	Core
	Avg.		**0.124**	**0.135**	**0.123**
		Std. Dev	**0.0046**	**0.0013**	**0.0045**
Lab	**0.124**	**0.0046**	1.000	**0.015**	0.691
Field	**0.135**	**0.0013**	**0.015**	1.000	**0.009**
Core	**0.123**	**0.0045**	0.691	**0.009**	1.000

Summer Slab, 60% PC/25% S/15% FA-180 day			Lab	Field	Core
	Avg.		**0.130**	**0.142**	**0.121**
		Std. Dev	**0.0041**	**0.0071**	**0.0009**
Lab	**0.130**	**0.0041**	1.000	**0.066**	**0.021**
Field	**0.142**	**0.0071**	**0.066**	1.000	**0.007**
Core	**0.121**	**0.0009**	**0.021**	**0.007**	1.000

Fall Slab, 100% PC-180 day			Lab	Field	Core
	Avg.		**0.119**	**0.123**	**0.127**
		Std. Dev	**0.0054**	**0.0015**	**0.0042**
Lab	**0.119**	**0.0054**	1.000	0.367	0.456
Field	**0.123**	**0.0015**	0.367	1.000	0.707
Core	**0.127**	**0.0042**	0.456	0.707	1.000

Fall Slab, 65% PC/35% S-180 day			Lab	Field	Core
	Avg.		**0.117**	**0.135**	**0.129**
		Std. Dev	**0.0048**	**0.0072**	**0.0079**
Lab	**0.117**	**0.0048**	1.000	**0.012**	**0.043**
Field	**0.135**	**0.0072**	**0.012**	1.000	**0.060**
Core	**0.129**	**0.0079**	**0.043**	**0.060**	1.000

Fall Slab, 60% PC/25% S/15% FA-180 day			Lab	Field	Core
	Avg.		**0.139**	**0.151**	**0.151**
		Std. Dev	**0.0014**	**0.0028**	**0.0037**
Lab	**0.139**	**0.0014**	1.000	**0.028**	**0.007**
Field	**0.151**	**0.0028**	**0.028**	1.000	0.867
Core	**0.151**	**0.0037**	**0.007**	0.867	1.000

Spring Slab, 100% PC-180 day			Lab	Field	Core
	Avg.		**0.100**	**0.110**	**0.102**
		Std. Dev	**0.0030**	**0.0051**	**0.0012**
Lab	**0.100**	**0.0030**	1.000	**0.040**	0.515
Field	**0.110**	**0.0051**	**0.040**	1.000	**0.043**
Core	**0.102**	**0.0012**	0.515	**0.043**	1.000

Spring Slab, 65% PC/35% S-180 day			Lab	Field	Core
	Avg.		**0.116**	**0.128**	**0.122**
		Std. Dev	**0.0018**	**0.0059**	**0.0052**
Lab	**0.116**	**0.0018**	1.000	**0.032**	0.156
Field	**0.128**	**0.0059**	**0.032**	1.000	0.257
Core	**0.122**	**0.0052**	0.156	0.257	1.000

Spring Slab, 60% PC/25% S/15% FA-180 day			Lab	Field	Core
	Avg.		**0.105**	**0.125**	**0.117**
		Std. Dev	**0.0042**	**0.0017**	**0.0104**
Lab	**0.105**	**0.0042**	1.000	**0.002**	0.144
Field	**0.125**	**0.0017**	**0.002**	1.000	0.251
Core	**0.117**	**0.0104**	0.144	0.251	1.000

Table B.11: Student's T-Test Results (p values) for 360-day Boil Test

Summer Slab, 100% PC-360 day			Lab	Field	Core
	Avg.		**0.117**	**0.141**	**0.134**
		Std. Dev	**0.0010**	**0.0070**	**0.0118**
Lab	**0.117**	**0.0010**	1.000	**0.004**	**0.065**
Field	**0.141**	**0.0070**	**0.004**	1.000	0.415
Core	**0.134**	**0.0118**	**0.065**	0.415	1.000

Summer Slab, 65% PC/35% S-360 day			Lab	Field	Core
	Avg.		**0.114**	**0.122**	**0.130**
		Std. Dev	**0.0013**	**0.0011**	**0.0059**
Lab	**0.114**	**0.0013**	1.000	**0.001**	**0.010**
Field	**0.122**	**0.0011**	**0.001**	1.000	0.102
Core	**0.130**	**0.0059**	**0.010**	0.102	1.000

Summer Slab, 60% PC/25% S/15% FA-360 day			Lab	Field	Core
	Avg.		**0.125**	**0.136**	**0.131**
		Std. Dev	**0.0008**	**0.0071**	**0.0048**
Lab	**0.125**	**0.0008**	1.000	**0.066**	0.114
Field	**0.136**	**0.0071**	**0.066**	1.000	0.392
Core	**0.131**	**0.0048**	0.114	0.392	1.000

Fall Slab, 100% PC-360 day			Lab	Field	Core
	Avg.		**0.117**	**0.121**	**0.118**
		Std. Dev	**0.0042**	**0.0022**	**0.0017**
Lab	**0.117**	**0.0042**	1.000	0.199	0.744
Field	**0.121**	**0.0022**	0.199	1.000	0.111
Core	**0.118**	**0.0017**	0.744	0.111	1.000

Fall Slab, 65% PC/35% S-360 day			Lab	Field	Core
	Avg.		**0.115**	**0.123**	**0.119**
		Std. Dev	**0.0053**	**0.0038**	**0.0030**
Lab	**0.115**	**0.0053**	1.000	**0.093**	0.338
Field	**0.123**	**0.0038**	**0.093**	1.000	0.189
Core	**0.119**	**0.0030**	0.338	0.189	1.000

Fall Slab, 60% PC/25% S/15% FA-360 day			Lab	Field	Core
	Avg.		**0.139**	**0.160**	**0.151**
		Std. Dev	**0.0020**	**0.0029**	**0.0050**
Lab	**0.139**	**0.0020**	1.000	**0.001**	**0.020**
Field	**0.160**	**0.0029**	**0.001**	1.000	**0.050**
Core	**0.151**	**0.0050**	**0.020**	**0.050**	1.000

Spring Slab, 100% PC-360 day			Lab	Field	Core
	Avg.		**0.106**	**0.116**	**0.108**
		Std. Dev	**0.0015**	**0.0023**	**0.0017**
Lab	**0.106**	**0.0015**	1.000	**0.003**	0.217
Field	**0.116**	**0.0023**	**0.003**	1.000	0.008
Core	**0.108**	**0.0017**	0.217	0.008	1.000

Spring Slab, 65% PC/35% S-360 day			Lab	Field	Core
	Avg.		**0.115**	**0.132**	**0.131**
		Std. Dev	**0.0035**	**0.0046**	**0.0051**
Lab	**0.115**	**0.0035**	1.000	**0.006**	**0.011**
Field	**0.132**	**0.0046**	**0.006**	1.000	0.711
Core	**0.131**	**0.0051**	**0.011**	0.711	1.000

Spring Slab, 60% PC/25% S/15% FA-360 day			Lab	Field	Core
	Avg.		**0.117**	**0.133**	**0.128**
		Std. Dev	**0.0014**	**0.0038**	**0.0102**
Lab	**0.117**	**0.0014**	1.000	**0.003**	0.153
Field	**0.133**	**0.0038**	**0.003**	1.000	0.499
Core	**0.128**	**0.0102**	0.153	0.499	1.000

Table B.12: Student's T-Test Results (*p* values) for 720-day Boil Test

Summer Slab, 100% PC-720 day			Lab	Field	Core
	Avg.		**0.118**	**0.135**	**0.128**
		Std. Dev	**0.0043**	**0.0039**	**0.0041**
Lab	**0.118**	**0.0043**	1.000	**0.008**	**0.048**
Field	**0.135**	**0.0039**	**0.008**	1.000	0.111
Core	**0.128**	**0.0041**	**0.048**	0.111	1.000

Summer Slab, 65% PC/35% S-720 day			Lab	Field	Core
	Avg.		**0.116**	**0.106**	**0.098**
		Std. Dev	**0.0008**	**0.0012**	**0.0027**
Lab	**0.116**	**0.0008**	1.000	**0.000**	**0.000**
Field	**0.106**	**0.0012**	**0.000**	1.000	**0.007**
Core	**0.098**	**0.0027**	**0.000**	**0.007**	1.000

Summer Slab, 60% PC/25% S/15% FA-720 day			Lab	Field	Core
	Avg.		**0.127**	**0.129**	**0.134**
		Std. Dev	**0.0018**	**0.0040**	**0.0069**
Lab	**0.127**	**0.0018**	1.000	0.466	0.167
Field	**0.129**	**0.0040**	0.466	1.000	0.348
Core	**0.134**	**0.0069**	0.167	0.348	1.000

Fall Slab, 100% PC-720 day			Lab	Field	Core
	Avg.		**0.112**	**0.121**	**0.133**
		Std. Dev	**0.0054**	**0.0015**	**0.0042**
Lab	**0.112**	**0.0054**	1.000	**0.059**	**0.007**
Field	**0.121**	**0.0015**	**0.059**	1.000	**0.010**
Core	**0.133**	**0.0042**	**0.007**	**0.010**	1.000

Fall Slab, 65% PC/35% S-720 day			Lab	Field	Core
	Avg.		**0.115**	**0.128**	**0.122**
		Std. Dev	**0.0048**	**0.0072**	**0.0079**
Lab	**0.115**	**0.0048**	1.000	**0.061**	0.226
Field	**0.128**	**0.0072**	**0.061**	1.000	0.439
Core	**0.122**	**0.0079**	0.226	0.439	1.000

Fall Slab, 60% PC/25% S/15% FA-720 day			Lab	Field	Core
	Avg.	**Std. Dev**	**0.137** **0.0014**	**0.151** **0.0028**	**0.153** **0.0037**
Lab	**0.137**	**0.0014**	1.000	**0.002**	**0.002**
Field	**0.151**	**0.0028**	**0.002**	1.000	0.509
Core	**0.153**	**0.0037**	**0.002**	0.509	1.000

Spring Slab, 100% PC-720 day			Lab	Field	Core
	Avg.	**Std. Dev**	**0.098** **0.0040**	**0.102** **0.0026**	**0.098** **0.0015**
Lab	**0.098**	**0.0040**	1.000	0.230	0.810
Field	**0.102**	**0.0026**	0.230	1.000	0.132
Core	**0.098**	**0.0015**	0.810	0.132	1.000

Spring Slab, 65% PC/35% S-720 day			Lab	Field	Core
	Avg.	**Std. Dev**	**0.105** **0.0019**	**0.118** **0.0035**	**0.125** **0.0077**
Lab	**0.105**	**0.0019**	1.000	**0.004**	**0.012**
Field	**0.118**	**0.0035**	**0.004**	1.000	0.260
Core	**0.125**	**0.0077**	**0.012**	0.260	1.000

Spring Slab, 60% PC/25% S/15% FA-720 day			Lab	Field	Core
	Avg.	**Std. Dev**	**0.106** **0.0016**	**0.130** **0.0035**	**0.116** **0.0034**
Lab	**0.106**	**0.0016**	1.000	**0.000**	**0.011**
Field	**0.130**	**0.0035**	**0.000**	1.000	**0.007**
Core	**0.116**	**0.0034**	**0.011**	**0.007**	1.000

Table B.13: Student's T-Test Results (p values) for 28-day RCP Test

Summer Slab, 100% PC-28 day			Lab	Field	Core
	Avg.		**2340**	**4120**	**3870**
		Std. Dev	**555**	**87**	**299**
Lab	**2340**	**555**	1.000	**0.005**	**0.014**
Field	**4120**	**87**	**0.005**	1.000	0.236
Core	**3870**	**299**	**0.014**	0.236	1.000

Summer Slab, 65% PC/35% S-28 day			Lab	Field	Core
	Avg.		**1370**	**2770**	**1770**
		Std. Dev	**206**	**78**	**507**
Lab	**1370**	**206**	1.000	**0.000**	0.267
Field	**2770**	**78**	**0.000**	1.000	**0.028**
Core	**1770**	**507**	0.267	**0.028**	1.000

Summer Slab, 60% PC/25% S/15% FA-28 day			Lab	Field	Core
	Avg.		**1560**	**3440**	**1590**
		Std. Dev	**272**	**539**	**211**
Lab	**1560**	**272**	1.000	**0.006**	0.881
Field	**3440**	**539**	**0.006**	1.000	**0.005**
Core	**1590**	**211**	0.881	**0.005**	1.000

Fall Slab, 100% PC-28 day			Lab	Field	Core
	Avg.		**3590**	**5130**	**4610**
		Std. Dev	**538**	**546**	**81**
Lab	**3590**	**538**	1.000	**0.025**	**0.031**
Field	**5130**	**546**	**0.025**	1.000	0.179
Core	**4610**	**81**	**0.031**	0.179	1.000

Fall Slab, 65% PC/35% S-28 day			Lab	Field	Core
	Avg.		**1740**	**2940**	**1990**
		Std. Dev	**20**	**296**	**67**
Lab	**1740**	**20**	1.000	**0.002**	**0.003**
Field	**2940**	**296**	**0.002**	1.000	**0.006**
Core	**1990**	**67**	**0.003**	**0.006**	1.000

Fall Slab, 60% PC/25% S/15% FA-28 day			Lab	Field	Core
	Avg.		**2460**	**4110**	**3710**
		Std. Dev	**133**	**324**	**26**
Lab	**2460**	**133**	1.000	**0.001**	**0.000**
Field	**4110**	**324**	**0.001**	1.000	**0.098**
Core	**3710**	**26**	**0.000**	**0.098**	1.000

Spring Slab, 100% PC-28 day			Lab	Field	Core
	Avg.		**2880**	**3900**	**2730**
		Std. Dev	**122**	**508**	**94**
Lab	**2880**	**122**	1.000	0.111	0.202
Field	**3900**	**508**	0.111	1.000	**0.024**
Core	**2730**	**94**	0.202	**0.024**	1.000

Spring Slab, 65% PC/35% S-28 day			Lab	Field	Core
	Avg.		**1580**	**2690**	**2230**
		Std. Dev	**24**	**49**	**235**
Lab	**1580**	**24**	1.000	**0.000**	**0.009**
Field	**2690**	**49**	**0.000**	1.000	**0.029**
Core	**2230**	**235**	**0.009**	**0.029**	1.000

Spring Slab, 60% PC/25% S/15% FA-28 day			Lab	Field	Core
	Avg.		**1600**	**2010**	**1740**
		Std. Dev	**141**	**269**	**536**
Lab	**1600**	**141**	1.000	**0.077**	0.685
Field	**2010**	**269**	**0.077**	1.000	0.472
Core	**1740**	**536**	0.685	0.472	1.000

Table B.14: Student's T-Test Results (*p* values) for 56-day RCP Test

Summer Slab, 100% PC-56 day			Lab	Field	Core
	Avg.		**2910**	**4410**	**3440**
		Std. Dev	**127**	**1119**	**991**
Lab	**2910**	**127**	1.000	**0.083**	0.413
Field	**4410**	**1119**	**0.083**	1.000	0.325
Core	**3440**	**991**	0.413	0.325	1.000

Summer Slab, 65% PC/35% S-56 day			Lab	Field	Core
	Avg.		**1330**	**1880**	**1420**
		Std. Dev	**135**	**255**	**61**
Lab	**1330**	**135**	1.000	**0.024**	0.333
Field	**1880**	**255**	**0.024**	1.000	**0.031**
Core	**1420**	**61**	0.333	**0.031**	1.000

Summer Slab, 60% PC/25% S/15% FA-56 day			Lab	Field	Core
	Avg.		**1270**	**2620**	**1540**
		Std. Dev	**163**	**181**	**183**
Lab	**1270**	**163**	1.000	**0.001**	0.124
Field	**2620**	**181**	**0.001**	1.000	**0.002**
Core	**1540**	**183**	0.124	**0.002**	1.000

Fall Slab, 100% PC-56 day			Lab	Field	Core
	Avg.		**3070**	**4220**	**4120**
		Std. Dev	**132**	**363**	**127**
Lab	**3070**	**132**	1.000	**0.007**	**0.001**
Field	**4220**	**363**	**0.007**	1.000	0.674
Core	**4120**	**127**	**0.001**	0.674	1.000

Fall Slab, 65% PC/35% S-56 day			Lab	Field	Core
	Avg.		**1290**	**1410**	**1550**
		Std. Dev	**77**	**143**	**76**
Lab	**1290**	**77**	1.000	0.275	**0.015**
Field	**1410**	**143**	0.275	1.000	0.210
Core	**1550**	**76**	**0.015**	0.210	1.000

Fall Slab, 60% PC/25% S/15% FA-56 day			Lab	Field	Core
	Avg.		**1800**	**3490**	**3550**
		Std. Dev	**112**	**295**	**348**
Lab	**1800**	**112**	1.000	**0.001**	**0.001**
Field	**3490**	**295**	**0.001**	1.000	0.840
Core	**3550**	**348**	**0.001**	0.840	1.000

Spring Slab, 100% PC-56 day			Lab	Field	Core
	Avg.		**2040**	**2380**	**1740**
		Std. Dev	**47**	**234**	**276**
Lab	**2040**	**47**	1.000	**0.070**	0.137
Field	**2380**	**234**	**0.070**	1.000	**0.038**
Core	**1740**	**276**	0.137	**0.038**	1.000

Spring Slab, 65% PC/35% S-56 day			Lab	Field	Core
	Avg.		**1050**	**1690**	**1490**
		Std. Dev	**27**	**193**	**234**
Lab	**1050**	**27**	1.000	**0.003**	**0.032**
Field	**1690**	**193**	**0.003**	1.000	0.215
Core	**1490**	**234**	**0.032**	0.215	1.000

Spring Slab, 60% PC/25% S/15% FA-56 day			Lab	Field	Core
	Avg.		**1170**	**1810**	**1270**
		Std. Dev	**87**	**222**	**90**
Lab	**1170**	**87**	1.000	**0.010**	0.230
Field	**1810**	**222**	**0.010**	1.000	**0.018**
Core	**1270**	**90**	0.230	**0.018**	1.000

Table B.15: Student's T-Test Results (*p* values) for 90-day RCP Test

Summer Slab, 100% PC-90 day			Lab	Field	Core
	Avg.		**2530**	**4070**	**2960**
		Std. Dev	**189**	**197**	**819**
Lab	**2530**	**189**	1.000	**0.001**	0.423
Field	**4070**	**197**	**0.001**	1.000	**0.084**
Core	**2960**	**819**	0.423	**0.084**	1.000

Summer Slab, 65% PC/35% S-90 day			Lab	Field	Core
	Avg.		**1180**	**1810**	**2010**
		Std. Dev	**13**	**29**	**510**
Lab	**1180**	**13**	1.000	**0.000**	**0.049**
Field	**1810**	**29**	**0.000**	1.000	0.554
Core	**2010**	**510**	**0.049**	0.554	1.000

Summer Slab, 60% PC/25% S/15% FA-90 day			Lab	Field	Core
	Avg.		**1420**	**2380**	**1690**
		Std. Dev	**116**	**243**	**76**
Lab	**1420**	**116**	1.000	**0.004**	0.226
Field	**2380**	**243**	**0.004**	1.000	**0.022**
Core	**1690**	**76**	0.226	**0.022**	1.000

Fall Slab, 100% PC-90 day			Lab	Field	Core
	Avg.		**2370**	**3320**	**4500**
		Std. Dev	**72**	**287**	**167**
Lab	**2370**	**72**	1.000	**0.005**	**0.000**
Field	**3320**	**287**	**0.005**	1.000	**0.004**
Core	**4500**	**167**	**0.000**	**0.004**	1.000

Fall Slab, 65% PC/35% S-90 day			Lab	Field	Core
	Avg.		**1180**	**1520**	**1670**
		Std. Dev	**102**	**146**	**27**
Lab	**1180**	**102**	1.000	**0.030**	**0.001**
Field	**1520**	**146**	**0.030**	1.000	0.164
Core	**1670**	**27**	**0.001**	0.164	1.000

Fall Slab, 60% PC/25% S/15% FA-90 day			Lab	Field	Core
	Avg.	**Std. Dev**	**1560** **147**	**3000** **190**	**2700** **128**
Lab	**1560**	**147**	1.000	**0.000**	**0.001**
Field	**3000**	**190**	**0.000**	1.000	**0.080**
Core	**2700**	**128**	**0.001**	**0.080**	1.000

Spring Slab, 100% PC-90 day			Lab	Field	Core
	Avg.	**Std. Dev**	**1880** **89**	**2540** **127**	**1850** **155**
Lab	**1880**	**89**	1.000	**0.002**	0.793
Field	**2540**	**127**	**0.002**	1.000	**0.004**
Core	**1850**	**155**	0.793	**0.004**	1.000

Spring Slab, 65% PC/35% S-90 day			Lab	Field	Core
	Avg.	**Std. Dev**	**1080** **27**	**1730** **134**	**1140** **307**
Lab	**1080**	**27**	1.000	**0.001**	0.744
Field	**1730**	**134**	**0.001**	1.000	**0.038**
Core	**1140**	**307**	0.744	**0.038**	1.000

Spring Slab, 60% PC/25% S/15% FA-90 day			Lab	Field	Core
	Avg.	**Std. Dev**	**1140** **77**	**1550** **352**	**1190** **95**
Lab	**1140**	**77**	1.000	0.119	0.564
Field	**1550**	**352**	0.119	1.000	0.156
Core	**1190**	**95**	0.564	0.156	1.000

Table B.16: Student's T-Test Results (*p* values) for 180-day RCP Test

Summer Slab, 100% PC-180 day			Lab	Field	Core
	Avg.		**2100**	**4030**	**3950**
		Std. Dev	**199**	**647**	**530**
Lab	**2100**	**199**	1.000	**0.008**	**0.005**
Field	**4030**	**647**	**0.008**	1.000	0.889
Core	**3950**	**530**	**0.005**	0.889	1.000

Summer Slab, 65% PC/35% S-180 day			Lab	Field	Core
	Avg.		**1170**	**1230**	**1130**
		Std. Dev	**65**	**43**	**201**
Lab	**1170**	**65**	1.000	0.249	0.757
Field	**1230**	**43**	0.249	1.000	0.444
Core	**1130**	**201**	0.757	0.444	1.000

Summer Slab, 60% PC/25% S/15% FA-180 day			Lab	Field	Core
	Avg.		**1110**	**1690**	**1540**
		Std. Dev	**180**	**181**	**71**
Lab	**1110**	**180**	1.000	**0.017**	**0.018**
Field	**1690**	**181**	**0.017**	1.000	0.254
Core	**1540**	**71**	**0.018**	0.254	1.000

Fall Slab, 100% PC-180 day			Lab	Field	Core
	Avg.		**2470**	**3130**	**3540**
		Std. Dev	**188**	**179**	**208**
Lab	**2470**	**188**	1.000	**0.012**	**0.003**
Field	**3130**	**179**	**0.012**	1.000	**0.060**
Core	**3540**	**208**	**0.003**	**0.060**	1.000

Fall Slab, 65% PC/35% S-180 day			Lab	Field	Core
	Avg.		**780**	**950**	**1040**
		Std. Dev	**36**	**73**	**24**
Lab	**780**	**36**	1.000	**0.022**	**0.001**
Field	**950**	**73**	**0.022**	1.000	0.134
Core	**1040**	**24**	**0.001**	0.134	1.000

Fall Slab, 60% PC/25% S/15% FA-180 day			Lab	Field	Core
	Avg.		**1000**	**2050**	**1420**
		Std. Dev	**31**	**229**	**76**
Lab	**1000**	**31**	1.000	**0.001**	**0.001**
Field	**2050**	**229**	**0.001**	1.000	**0.010**
Core	**1420**	**76**	**0.001**	**0.010**	1.000

Spring Slab, 100% PC-180 day			Lab	Field	Core
	Avg.		**1700**	**2560**	**1690**
		Std. Dev	**34**	**28**	**106**
Lab	**1700**	**34**	1.000	**0.000**	0.922
Field	**2560**	**28**	**0.000**	1.000	**0.000**
Core	**1690**	**106**	0.922	**0.000**	1.000

Spring Slab, 65% PC/35% S-180 day			Lab	Field	Core
	Avg.		**900**	**1480**	**1070**
		Std. Dev	**82**	**43**	**158**
Lab	**900**	**82**	1.000	**0.000**	0.176
Field	**1480**	**43**	**0.000**	1.000	**0.013**
Core	**1070**	**158**	0.176	**0.013**	1.000

Spring Slab, 60% PC/25% S/15% FA-180 day			Lab	Field	Core
	Avg.		**900**	**1470**	**1070**
		Std. Dev	**76**	**61**	**307**
Lab	**900**	**76**	1.000	**0.001**	0.389
Field	**1470**	**61**	**0.001**	1.000	**0.092**
Core	**1070**	**307**	0.389	**0.092**	1.000

Table B.17: Student's T-Test Results (*p* values) for 360-day RCP Test

Summer Slab, 100% PC-360 day			Lab	Field	Core
	Avg.		**2000**	**3310**	**4680**
		Std. Dev	**204**	**298**	**589**
Lab	**2000**	**204**	1.000	**0.013**	**0.010**
Field	**3310**	**298**	**0.013**	1.000	**0.023**
Core	**4680**	**589**	**0.010**	**0.023**	1.000

Summer Slab, 65% PC/35% S-360 day			Lab	Field	Core
	Avg.		**790**	**1180**	**940**
		Std. Dev	**10**	**16**	**262**
Lab	**790**	**10**	1.000	**0.000**	0.386
Field	**1180**	**16**	**0.000**	1.000	0.190
Core	**940**	**262**	0.386	0.190	1.000

Summer Slab, 60% PC/25% S/15% FA-360 day			Lab	Field	Core
	Avg.		**820**	**1280**	**950**
		Std. Dev	**80**	**259**	**155**
Lab	**820**	**80**	1.000	**0.041**	0.260
Field	**1280**	**259**	**0.041**	1.000	0.128
Core	**950**	**155**	0.260	0.128	1.000

Fall Slab, 100% PC-360 day			Lab	Field	Core
	Avg.		**1930**	**2940**	**2790**
		Std. Dev	**67**	**276**	**230**
Lab	**1930**	**67**	1.000	**0.004**	**0.003**
Field	**2940**	**276**	**0.004**	1.000	0.527
Core	**2790**	**230**	**0.003**	0.527	1.000

Fall Slab, 65% PC/35% S-360 day			Lab	Field	Core
	Avg.		**770**	**1110**	**750**
		Std. Dev	**34**	**158**	**48**
Lab	**770**	**34**	1.000	**0.022**	0.478
Field	**1110**	**158**	**0.022**	1.000	**0.019**
Core	**750**	**48**	0.478	**0.019**	1.000

Fall Slab, 60% PC/25% S/15% FA-360 day			Lab	Field	Core
	Avg.		**930**	**1920**	**1220**
		Std. Dev	**9**	**66**	**223**
Lab	**930**	**9**	1.000	**0.000**	**0.082**
Field	**1920**	**66**	**0.000**	1.000	**0.007**
Core	**1220**	**223**	**0.082**	**0.007**	1.000

Spring Slab, 100% PC-360 day			Lab	Field	Core
	Avg.		**1470**	**2270**	**1690**
		Std. Dev	**144**	**105**	**138**
Lab	**1470**	**144**	1.000	**0.001**	0.126
Field	**2270**	**105**	**0.001**	1.000	**0.004**
Core	**1690**	**138**	0.126	**0.004**	1.000

Spring Slab, 65% PC/35% S-360 day			Lab	Field	Core
	Avg.		**940**	**1690**	**1530**
		Std. Dev	**100**	**193**	**247**
Lab	**940**	**100**	1.000	**0.004**	**0.019**
Field	**1690**	**193**	**0.004**	1.000	0.425
Core	**1530**	**247**	**0.019**	0.425	1.000

Spring Slab, 60% PC/25% S/15% FA-360 day			Lab	Field	Core
	Avg.		**830**	**1220**	**1340**
		Std. Dev	**47**	**75**	**273**
Lab	**830**	**47**	1.000	**0.002**	**0.033**
Field	**1220**	**75**	**0.002**	1.000	0.512
Core	**1340**	**273**	**0.033**	0.512	1.000

Table B.18: Student's T-Test Results (p values) for 720-day RCP Test

Summer Slab, 100% PC-720 day			Lab	Field	Core
	Avg.		**1920**	**3130**	**4770**
		Std. Dev	**36**	**433**	**164**
Lab	**1920**	**36**	1.000	**0.008**	**0.000**
Field	**3130**	**433**	**0.008**	1.000	**0.004**
Core	**4770**	**164**	**0.000**	**0.004**	1.000

Summer Slab, 65% PC/35% S-720 day			Lab	Field	Core
	Avg.		**720**	**1150**	**1460**
		Std. Dev	**176**	**60**	**338**
Lab	**720**	**176**	1.000	**0.017**	**0.028**
Field	**1150**	**60**	**0.017**	1.000	**0.185**
Core	**1460**	**338**	**0.028**	**0.185**	1.000

Summer Slab, 60% PC/25% S/15% FA-720 day			Lab	Field	Core
	Avg.		**740**	**1150**	**1030**
		Std. Dev	**41**	**170**	**123**
Lab	**740**	**41**	1.000	**0.016**	**0.018**
Field	**1150**	**170**	**0.016**	1.000	**0.386**
Core	**1030**	**123**	**0.018**	**0.386**	1.000

Fall Slab, 100% PC-720 day			Lab	Field	Core
	Avg.		**1860**	**2740**	**2540**
		Std. Dev	**108**	**234**	**403**
Lab	**1860**	**108**	1.000	**0.004**	**0.047**
Field	**2740**	**234**	**0.004**	1.000	0.494
Core	**2540**	**403**	**0.047**	0.494	1.000

Fall Slab, 65% PC/35% S-720 day			Lab	Field	Core
	Avg.		**650**	**940**	**600**
		Std. Dev	**13**	**171**	**25**
Lab	**650**	**13**	1.000	**0.044**	**0.028**
Field	**940**	**171**	**0.044**	1.000	**0.027**
Core	**600**	**25**	**0.028**	**0.027**	1.000

Fall Slab, 60% PC/25% S/15% FA-720 day			Lab	Field	Core
	Avg.		**810**	**1390**	**1060**
		Std. Dev	**66**	**29**	**81**
Lab	**810**	**66**	1.000	**0.000**	**0.015**
Field	**1390**	**29**	**0.000**	1.000	**0.002**
Core	**1060**	**81**	**0.015**	**0.002**	1.000

Spring Slab, 100% PC-720 day			Lab	Field	Core
	Avg.		**1310**	**1810**	**1500**
		Std. Dev	**134**	**77**	**474**
Lab	**1310**	**134**	1.000	**0.005**	0.537
Field	**1810**	**77**	**0.005**	1.000	0.331
Core	**1500**	**474**	0.537	0.331	1.000

Spring Slab, 65% PC/35% S-720 day			Lab	Field	Core
	Avg.		**680**	**1100**	**1070**
		Std. Dev	**47**	**95**	**80**
Lab	**680**	**47**	1.000	**0.002**	**0.002**
Field	**1100**	**95**	**0.002**	1.000	0.676
Core	**1070**	**80**	**0.002**	0.676	1.000

Spring Slab, 60% PC/25% S/15% FA-720 day			Lab	Field	Core
	Avg.		**620**	**950**	**700**
		Std. Dev	**38**	**82**	**84**
Lab	**620**	**38**	1.000	**0.003**	0.199
Field	**950**	**82**	**0.003**	1.000	**0.022**
Core	**700**	**84**	0.199	**0.022**	1.000

Table B.19: Student's T-Test Comparison (p values) for Compressive Strength for 100% Portland Cement Slabs at 28 Days

Lab					
			SUMMER, 100% PC	FALL, 100% PC	SPRING, 100% PC
	Avg.		4490	5230	6780
		Std. Dev	207.9	95.4	258.1
SUMMER, 100% PC	4490	207.9	1	**0.005**	**0.0003**
FALL, 100% PC	5230	95.4	**0.005**	1	**0.0006**
SPRING, 100% PC	6780	258.1	**0.0003**	**0.0006**	1
Field					
			SUMMER, 100% PC	FALL, 100% PC	SPRING, 100% PC
	Avg.		4160	4820	6980
		Std. Dev	370.7	580.3	457.4
SUMMER, 100% PC	4160	370.7	1	0.174	**0.001**
FALL, 100% PC	4820	580.3	0.174	1	**0.007**
SPRING, 100% PC	6980	457.4	**0.001**	**0.007**	1
Core					
			SUMMER, 100% PC	FALL, 100% PC	SPRING, 100% PC
	Avg.		4300	4730	5760
		Std. Dev	325.1	485.4	396.0
SUMMER, 100% PC	4300	325.1	1	0.271	**0.013**
FALL, 100% PC	4730	485.4	0.271	1	**0.057**
SPRING, 100% PC	5760	396.0	**0.013**	**0.057**	1

Table B.20: Student's T-Test Comparison (*p* values) for Compressive Strength for 65% Portland Cement/35% Slag Slabs at 28 Days

Lab					
			SUMMER, 65% PC/35% S	FALL, 65% PC/35% S	SPRING, 65% PC/35% S
	Avg.		5610	5450	6130
		Std. Dev	658.5	468.2	525.2
SUMMER, 65% PC/35% S	5610	658.5	1	0.744	0.348
FALL, 65% PC/35% S	5450	468.2	0.744	1	0.169
SPRING, 65% PC/35% S	6130	525.2	0.348	0.169	1
Field					
			SUMMER, 65% PC/35% S	FALL, 65% PC/35% S	SPRING, 65% PC/35% S
	Avg.		4630	5690	5270
		Std. Dev	427.1	345.9	148.0
SUMMER, 65% PC/35% S	4630	427.1	1	**0.029**	**0.071**
FALL, 65% PC/35% S	5690	345.9	**0.029**	1	0.128
SPRING, 65% PC/35% S	5270	148.0	**0.071**	0.128	1
Core					
			SUMMER, 65% PC/35% S	FALL, 65% PC/35% S	SPRING, 65% PC/35% S
	Avg.		4890	5560	5610
		Std. Dev	801.4	337.1	423.6
SUMMER, 65% PC/35% S	4890	801.4	1	0.253	0.237
FALL, 65% PC/35% S	5560	337.1	0.253	1	0.865
SPRING, 65% PC/35% S	5610	423.6	0.237	0.865	1

Table B.21: Student's T-Test Comparison (*p* values) for Compressive Strength for 60% Portland Cement/25% Slag/15% Fly Ash (PC/S/FA) Slabs at 28 Days

Lab					
			SUMMER, 60% PC/25% S/15% FA	FALL, 60% PC/25% S/15% FA	SPRING, 60% PC/25% S/15% FA
	Avg.		5160	4380	5490
		Std. Dev	58.6	252.4	452.1
SUMMER, 60% PC/25% S/15% FA	5160	58.6	1	**0.006**	0.282
FALL, 60% PC/25% S/15% FA	4380	252.4	**0.006**	1	**0.021**
SPRING, 60% PC/25% S/15% FA	5490	452.1	0.282	**0.021**	1
Field					
			SUMMER, 60% PC/25% S/15% FA	FALL, 60% PC/25% S/15% FA	SPRING, 60% PC/25% S/15% FA
	Avg.		4070	3470	5120
		Std. Dev	306.1	729.6	287.5
SUMMER, 60% PC/25% S/15% FA	4070	306.1	1	0.259	**0.012**
FALL, 60% PC/25% S/15% FA	3470	729.6	0.259	1	**0.022**
SPRING, 60% PC/25% S/15% FA	5120	287.5	**0.012**	**0.022**	1
Core					
			SUMMER, 60% PC/25% S/15% FA	FALL, 60% PC/25% S/15% FA	SPRING, 60% PC/25% S/15% FA
	Avg.		5170	4070	5120
		Std. Dev	410.2	162.9	473.8
SUMMER, 60% PC/25% S/15% FA	5170	410.2	1	**0.012**	0.910
FALL, 60% PC/25% S/15% FA	4070	162.9	**0.012**	1	**0.022**
SPRING, 60% PC/25% S/15% FA	5120	473.8	0.910	**0.022**	1

Table B.22: Student's T-Test Comparison (p values) for Boil Test for 100% Portland Cement Slabs at 28 Days

Lab					
			SUMMER, 100% PC	FALL, 100% PC	SPRING, 100% PC
	Avg.		12.5%	12.4%	11.1%
		Std. Dev	0.26%	0.11%	0.10%
SUMMER, 100% PC	12.5%	0.26%	1	0.531	**0.001**
FALL, 100% PC	12.4%	0.11%	0.531	1	**0.000**
SPRING, 100% PC	11.1%	0.10%	**0.001**	**0.000**	1
Field					
			SUMMER, 100% PC	FALL, 100% PC	SPRING, 100% PC
	Avg.		13.6%	13.2%	12.2%
		Std. Dev	1.11%	0.29%	0.65%
SUMMER, 100% PC	13.6%	1.11%	1	0.535	0.134
FALL, 100% PC	13.2%	0.29%	0.535	1	**0.082**
SPRING, 100% PC	12.2%	0.65%	0.134	**0.082**	1
Core					
			SUMMER, 100% PC	FALL, 100% PC	SPRING, 100% PC
	Avg.		12.7%	13.0%	11.5%
		Std. Dev	0.34%	0.67%	0.37%
SUMMER, 100% PC	12.7%	0.34%	1	0.572	**0.015**
FALL, 100% PC	13.0%	0.67%	0.572	1	**0.031**
SPRING, 100% PC	11.5%	0.37%	**0.015**	**0.031**	1

Table B.23: Student's T-Test Comparison (*p* values) for Boil Test for 65% Portland Cement/35% Slag (PC/S) Slabs at 28 Days

Lab					
			SUMMER, 65% PC/35% S	FALL, 65% PC/35% S	SPRING, 65% PC/35% S
	Avg.		12.2%	11.8%	11.6%
		Std. Dev	0.13%	0.23%	0.33%
SUMMER, 65% PC/35% S	12.2%	0.13%	1	**0.057**	**0.035**
FALL, 65% PC/35% S	11.8%	0.23%	**0.057**	1	0.364
SPRING, 65% PC/35% S	11.6%	0.33%	**0.035**	0.364	1
Field					
			SUMMER, 65% PC/35% S	FALL, 65% PC/35% S	SPRING, 65% PC/35% S
	Avg.		13.2%	13.0%	13.3%
		Std. Dev	0.29%	0.31%	0.37%
SUMMER, 65% PC/35% S	13.2%	0.29%	1	0.557	0.774
FALL, 65% PC/35% S	13.0%	0.31%	0.557	1	0.438
SPRING, 65% PC/35% S	13.3%	0.37%	0.774	0.438	1
Core					
			SUMMER, 65% PC/35% S	FALL, 65% PC/35% S	SPRING, 65% PC/35% S
	Avg.		13.3%	12.3%	12.8%
		Std. Dev	0.64%	0.09%	0.15%
SUMMER, 65% PC/35% S	13.3%	0.64%	1	**0.060**	0.256
FALL, 65% PC/35% S	12.3%	0.09%	**0.060**	1	**0.010**
SPRING, 65% PC/35% S	12.8%	0.15%	0.256	**0.010**	1

Table B.24: Student's T-Test Comparison (p values) for Boil Test for 60% Portland Cement/25% Slag/15% Fly Ash (PC/S/FA) Slabs at 28 Days

Lab					
			SUMMER, 60% PC/25% S/15% FA	FALL, 60% PC/25% S/15% FA	SPRING, 60% PC/25% S/15% FA
	Avg.		12.9%	14.6%	11.4%
		Std. Dev	0.36%	0.19%	0.13%
SUMMER, 60% PC/25% S/15% FA	12.9%	0.36%	1	**0.002**	**0.003**
FALL, 60% PC/25% S/15% FA	14.6%	0.19%	**0.002**	1	**0.000**
SPRING, 60% PC/25% S/15% FA	11.4%	0.13%	**0.003**	**0.000**	1
Field					
			SUMMER, 60% PC/25% S/15% FA	FALL, 60% PC/25% S/15% FA	SPRING, 60% PC/25% S/15% FA
	Avg.		14.6%	17.3%	12.7%
		Std. Dev	0.33%	0.67%	0.40%
SUMMER, 60% PC/25% S/15% FA	14.6%	0.33%	1	**0.003**	**0.004**
FALL, 60% PC/25% S/15% FA	17.3%	0.67%	**0.003**	1	**0.001**
SPRING, 60% PC/25% S/15% FA	12.7%	0.40%	**0.004**	**0.001**	1
Core					
			SUMMER, 60% PC/25% S/15% FA	FALL, 60% PC/25% S/15% FA	SPRING, 60% PC/25% S/15% FA
	Avg.		13.6%	15.3%	11.9%
		Std. Dev	0.56%	0.63%	0.22%
SUMMER, 60% PC/25% S/15% FA	13.6%	0.56%	1	**0.024**	**0.010**
FALL, 60% PC/25% S/15% FA	15.3%	0.63%	**0.024**	1	**0.001**
SPRING, 60% PC/25% S/15% FA	11.9%	0.22%	**0.010**	**0.001**	1

Table B.25: Student's T-Test Comparison (p values) for RCP Test for 100% Portland Cement Slabs at 28 Days

Lab					
			SUMMER, 100% PC	FALL, 100% PC	SPRING, 100% PC
	Avg.	**Std. Dev**	2340 555	3590 538	2880 122
SUMMER, 100% PC	2340	555	1	**0.050**	0.288
FALL, 100% PC	3590	538	**0.050**	1	0.182
SPRING, 100% PC	2880	122	0.288	0.182	1
Field					
			SUMMER, 100% PC	FALL, 100% PC	SPRING, 100% PC
	Avg.	**Std. Dev**	4120 87	5130 546	3900 508
SUMMER, 100% PC	4120	87	1	**0.034**	0.489
FALL, 100% PC	5130	546	**0.034**	1	**0.086**
SPRING, 100% PC	3900	508	0.489	**0.086**	1
Core					
			SUMMER, 100% PC	FALL, 100% PC	SPRING, 100% PC
	Avg.	**Std. Dev**	3870 299	4610 81	2730 94
SUMMER, 100% PC	3870	299	1	**0.014**	**0.003**
FALL, 100% PC	4610	81	**0.014**	1	**0.000**
SPRING, 100% PC	2730	94	**0.003**	**0.000**	1

Table B.26: Student's T-Test Comparison (p values) for RCP Test for 65% Portland Cement/35% Slag Slabs at 28 Days

Lab					
			SUMMER, 65% PC/35% S	FALL, 65% PC/35% S	SPRING, 65% PC/35% S
	Avg.	**Std. Dev**	1370 206	1740 20	1580 24
SUMMER, 65% PC/35% S	1370	206	1	**0.036**	0.143
FALL, 65% PC/35% S	1740	20	**0.036**	1	**0.001**
SPRING, 65% PC/35% S	1580	24	0.143	**0.001**	1
Field					
			SUMMER, 65% PC/35% S	FALL, 65% PC/35% S	SPRING, 65% PC/35% S
	Avg.	**Std. Dev**	2770 78	2940 296	2690 49
SUMMER, 65% PC/35% S	2770	78	1	0.407	0.188
FALL, 65% PC/35% S	2940	296	0.407	1	0.226
SPRING, 65% PC/35% S	2690	49	0.188	0.226	1
Core					
			SUMMER, 65% PC/35% S	FALL, 65% PC/35% S	SPRING, 65% PC/35% S
	Avg.	**Std. Dev**	1770 507	1990 67	2230 235
SUMMER, 65% PC/35% S	1770	507	1	0.499	0.230
FALL, 65% PC/35% S	1990	67	0.499	1	0.168
SPRING, 65% PC/35% S	2230	235	0.230	0.168	1

Table B.27: Student's T-Test Comparison (p values) for RCP Test for 60% Portland Cement/25% Slag/15% Fly Ash (PC/S/FA) Slabs at 28 Days

Lab					
			SUMMER, 60% PC/25% S/15% FA	FALL, 60% PC/25% S/15% FA	SPRING, 60% PC/25% S/15% FA
	Avg.		1560	2460	1600
		Std. Dev	272	133	141
SUMMER, 60% PC/25% S/15% FA	1560	272	1	**0.007**	0.829
FALL, 60% PC/25% S/15% FA	2460	133	**0.007**	1	**0.002**
SPRING, 60% PC/25% S/15% FA	1600	141	0.829	**0.002**	1
Field					
			SUMMER, 60% PC/25% S/15% FA	FALL, 60% PC/25% S/15% FA	SPRING, 60% PC/25% S/15% FA
	Avg.		3440	4110	2010
		Std. Dev	112	324	269
SUMMER, 60% PC/25% S/15% FA	3440	112	1	0.138	**0.015**
FALL, 60% PC/25% S/15% FA	4110	324	0.138	1	**0.001**
SPRING, 60% PC/25% S/15% FA	2010	269	**0.015**	**0.001**	1
Core					
			SUMMER, 60% PC/25% S/15% FA	FALL, 60% PC/25% S/15% FA	SPRING, 60% PC/25% S/15% FA
	Avg.		1590	3710	1740
		Std. Dev	211	26	536
SUMMER, 60% PC/25% S/15% FA	1590	211	1	**0.000**	0.677
FALL, 60% PC/25% S/15% FA	3710	26	**0.000**	1	**0.003**
SPRING, 60% PC/25% S/15% FA	1740	536	0.677	**0.003**	1

Table B.28: Student's T-Test Comparison (*p* values) for Compressive Strength for Fall Slab, 60% PC/25% S/15% FA, at 28 Days

	Lab	Field	Core
SUMMER, 100% PC	0.581	0.216	0.329
FALL, 100% PC	**0.005**	**0.066**	**0.088**
SPRING, 100% PC	**0.0003**	**0.002**	**0.004**
SUMMER, 65% PC/35% S	**0.039**	**0.076**	0.157
FALL, 65% PC/35% S	**0.026**	**0.009**	**0.002**
SPRING, 65% PC/35% S	**0.007**	**0.014**	**0.004**
SUMMER, 60% PC/25% S/15% FA	**0.002**	**0.003**	**0.024**
FALL, 60% PC/25% S/15% FA	1.000	1.000	1.000
SPRING, 60% PC/25% S/15% FA	**0.0000**	**0.0005**	**0.0010**

Table B.29: Student's T-Test Comparison (*p* values) for Boil Test for Fall Slab, 60% PC/25% S/15% FA, at 28 Days

	Lab	Field	Core
SUMMER, 100% PC	**0.0004**	**0.0076**	**0.0033**
FALL, 100% PC	**0.0001**	**0.0006**	**0.0124**
SPRING, 100% PC	**0.0000**	**0.0007**	**0.0009**
SUMMER, 65% PC/35% S	**0.0001**	**0.0006**	**0.0181**
FALL, 65% PC/35% S	**0.0001**	**0.0005**	**0.0013**
SPRING, 65% PC/35% S	**0.0002**	**0.0008**	**0.0026**
SUMMER, 60% PC/25% S/15% FA	**0.0022**	**0.0029**	**0.0244**
FALL, 60% PC/25% S/15% FA	1.000	1.000	1.000
SPRING, 60% PC/25% S/15% FA	**0.0000**	**0.0005**	**0.0010**

Table B.30: Student's T-Test Comparison (*p* values) for RCP Test for Fall Slab, 60% PC/25% S/15% FA, at 28 Days

	Lab	Field	Core
SUMMER, 100% PC	0.736	0.982	0.417
FALL, 100% PC	**0.025**	**0.050**	**0.0001**
SPRING, 100% PC	**0.038**	0.598	**0.0001**
SUMMER, 65% PC/35% S	**0.0015**	**0.0022**	**0.0027**
FALL, 65% PC/35% S	**0.0007**	**0.0097**	**0.0000**
SPRING, 65% PC/35% S	**0.0003**	**0.0017**	**0.0004**
SUMMER, 60% PC/25% S/15% FA	**0.007**	0.138	**0.0001**
FALL, 60% PC/25% S/15% FA	1.000	1.000	1.000
SPRING, 60% PC/25% S/15% FA	**0.0015**	**0.0010**	**0.0031**

APPENDIX C: Individual Strength, Boil, and RCP Data

Table C.1: Strength Data (psi), Summer Slab, 100% PC

Age	Sample Type	Sample			Average
		1	2	3	
28 day	Lab	4340	4730	4410	4490
	Field	3740	4320	4430	4160
	Core	4670	4170	4060	4300
56 day	Lab	5190	5780	5310	5430
	Field	4280	5320	4750	4780
	Core	4800	4660	5020	4830
90 day	Lab	5110	5580	5570	5420
	Field	4530	4390	5070	4660
	Core	5780	5110	5020	5300
180 day	Lab	5570	4930	5150	5220
	Field	3440	4330	3920	3900
	Core	3890	3670	4820	4130
360 day	Lab	5870	5950	5880	5900
	Field	5500	5990	4740	5410
	Core	5390	4520	4910	4940
720 day	Lab	5570	6210	5410	5730
	Field	5490	5170	4380	5010
	Core	4990	5130	5240	5120

Table C.2: Strength Data (psi), Summer Slab, 65% PC/35% S

Age	Sample Type	Sample 1	Sample 2	Sample 3	Average
28 day	Lab	4850	6010	5970	5610
	Field	4160	4750	4990	4630
	Core	4150	5740	4770	4890
56 day	Lab	6230	5560	5550	5780
	Field	4380	5360	4950	4900
	Core	5780	6090	6100	5990
90 day	Lab	6050	6030	6250	6110
	Field	4040	4660	4020	4240
	Core	5670	5220	5310	5400
180 day	Lab	5480	6260	6710	6150
	Field	4450	4810	3890	4380
	Core	5180	5560	5120	5290
360 day	Lab	6580	7090	6590	6750
	Field	5820	6490	6620	6310
	Core	6260	6220	6880	6450
720 day	Lab	6270	6550	7010	6610
	Field	5250	5730	6080	5690
	Core	5810	5870	5750	5810

Table C.3: Strength Data (psi), Summer Slab, 60% PC/25% S/15% FA

Age	Sample Type	Sample			Average
		1	2	3	
28 day	Lab	5120	5230	5140	5160
	Field	3780	4390	4040	4070
	Core	5630	5020	4850	5170
56 day	Lab	5150	4990	5450	5200
	Field	3770	4770	4090	4210
	Core	4310	4650	5850	4940
90 day	Lab	5640	5760	5130	5510
	Field	4270	4850	4950	4690
	Core	4790	5170	4890	4950
180 day	Lab	5640	5770	5860	5760
	Field	4190	5200	4570	4650
	Core	4310	4870	5200	4790
360 day	Lab	6430	6980	6830	6750
	Field	4810	6050	6060	5640
	Core	6460	5970	6670	6370
720 day	Lab	6740	6780	6220	6580
	Field	5850	5070	6130	5680
	Core	5320	6320	6710	6120

Table C.4: Strength Data (psi), Fall Slab, 100% PC

Age	Sample Type	Sample 1	Sample 2	Sample 3	Average
28 day	Lab	5320	5240	5130	5230
	Field	5050	5250	4160	4820
	Core	4870	5130	4190	4730
56 day	Lab	5820	5740	5240	5600
	Field	5070	5240	5810	5370
	Core	5230	5330	4980	5180
90 day	Lab	5380	6250	4970	5530
	Field	5370	5160	5170	5230
	Core	4750	4160	5060	4660
180 day	Lab	5690	6090	6600	6130
	Field	6090	6090	6170	6120
	Core	4690	6480	6290	5820
360 day	Lab	6110	6830	6810	6580
	Field	5410	6400	5800	5870
	Core	5420	5560	5950	5640
720 day	Lab	6690	5970	6350	6340
	Field	7270	6680	7090	7010
	Core	6110	6160	6140	6140

Table C.5: Strength Data (psi), Fall Slab, 65% PC/35% S

Age	Sample Type	Sample 1	Sample 2	Sample 3	Average
28 day	Lab	4950	5880	5510	5450
	Field	5310	5990	5760	5690
	Core	5870	5600	5200	5560
56 day	Lab	6470	6080	6520	6360
	Field	5760	6320	5240	5770
	Core	6840	5200	6050	6030
90 day	Lab	6930	6840	6170	6650
	Field	5860	6130	6140	6040
	Core	6590	6180	6250	6340
180 day	Lab	7360	7360	7290	7340
	Field	6560	7180	6600	6780
	Core	6760	5940	7100	6600
360 day	Lab	6860	6630	6850	6780
	Field	6080	6890	6930	6630
	Core	6450	7360	8140	7320
720 day	Lab	5500	6680	6660	6280
	Field	6330	6870	5560	6250
	Core	6670	8820	8400	7960

Table C.6: Strength Data (psi), Fall Slab, 60% PC/25% S/15% FA

Age	Sample Type	Sample			Average
		1	2	3	
28 day	Lab	4650	4150	4340	4380
	Field	3760	4010	2640	3470
	Core	3880	4140	4180	4070
56 day	Lab	4900	5090	5120	5040
	Field	4330	3950	4650	4310
	Core	4840	4290	4230	4450
90 day	Lab	5250	5630	4980	5290
	Field	3940	4020	4380	4110
	Core	4750	3790	4650	4400
180 day	Lab	4890	4730	5400	5010
	Field	4220	5050	4800	4690
	Core	4500	5420	5530	5150
360 day	Lab	4640	4480	5140	4750
	Field	5340	5360	5470	5390
	Core	5420	5850	5440	5570
720 day	Lab	5690	6330	6360	6130
	Field	6020	6220	4900	5710
	Core	6080	6190	6360	6210

Table C.7: Strength Data (psi), Spring Slab, 100% PC

Age	Sample Type	Sample 1	Sample 2	Sample 3	Average
28 day	Lab	6950	6480	6900	6780
	Field	7160	7320	6460	6980
	Core	6270	5300	5710	5760
56 day	Lab	6950	7360	6260	6860
	Field	7490	7060	5570	6710
	Core	5650	6590	7070	6440
90 day	Lab	7100	7010	7410	7170
	Field	7370	6820	7060	7080
	Core	6320	7530	7530	7130
180 day	Lab	8740	8120	5210	7360
	Field	6740	6510	6820	6690
	Core	7580	7210	7220	7340
360 day	Lab	7730	8570	7280	7860
	Field	6360	6700	7550	6870
	Core	7990	8010	8090	8030
720 day	Lab	6180			6180
	Field	7110	6180	5850	6380
	Core	6080	6860	5950	6300

Table C.8: Strength Data (psi), Spring Slab, 65% PC/35% S

Age	Sample Type	Sample 1	Sample 2	Sample 3	Average
28 day	Lab	5610	6110	6660	6130
	Field	5170	5200	5440	5270
	Core	5920	5790	5130	5610
56 day	Lab	5860	6070	6700	6210
	Field	5970	6540	5490	6000
	Core	6040	5550	5480	5690
90 day	Lab	6860	6780	6750	6800
	Field	5490	5840	5990	5770
	Core	6120	6030	5430	5860
180 day	Lab	7370	7370	7450	7400
	Field	5790	6300	5940	6010
	Core	6290	6700	6530	6510
360 day	Lab	7670	7270	6350	7100
	Field	5620	6810	5950	6130
	Core	7320	7430	7660	7470
720 day	Lab	6730	8080	6900	7240
	Field	6590	5820	6400	6270
	Core	5950	6690	6170	6270

Table C.9: Strength Data (psi), Spring Slab, 60% PC/25% S/15% FA

Age	Sample Type	Sample			Average
		1	2	3	
28 day	Lab	4990	5610	5870	5490
	Field	5020	4890	5440	5120
	Core	5670	4870	4830	5120
56 day	Lab	5720	5810	6310	5950
	Field	5550	5080	5160	5260
	Core	5570	6250	5140	5650
90 day	Lab	6400	5590	7010	6330
	Field	5400	6360	5790	5850
	Core	6650	5240	6100	6000
180 day	Lab	6900	6890	6080	6620
	Field	5830	5280	5790	5630
	Core	5360	6810	5650	5940
360 day	Lab	7090	6420	5660	6390
	Field	5870	6330	5800	6000
	Core	6220	6540	6150	6300
720 day	Lab	7770	6830	7520	7370
	Field	7510	7210	7660	7460
	Core	7310	7130	5620	6690

Table C.10: Boil Test Data (% voids), Summer Slab, 100% PC

Age	Sample Type	Sample 1	Sample 2	Sample 3	Average
28 day	Lab	12.8%	12.3%	12.4%	12.5%
	Field	14.9%	13.1%	12.8%	13.6%
	Core	12.8%	13.0%	12.3%	12.7%
56 day	Lab	13.1%	12.5%	12.6%	12.7%
	Field	14.3%	13.6%	14.3%	14.1%
	Core	13.4%	12.9%	13.4%	13.3%
90 day	Lab	12.4%	12.0%	12.9%	12.4%
	Field	14.9%	13.7%	14.4%	14.4%
	Core	12.8%	13.0%	13.9%	13.2%
180 day	Lab	12.7%	10.5%	12.0%	11.7%
	Field	13.9%	14.0%	13.7%	13.9%
	Core	11.9%	11.0%	11.6%	11.5%
360 day	Lab	11.6%	11.8%	11.7%	11.7%
	Field	14.4%	14.6%	13.3%	14.1%
	Core	13.5%	14.6%	12.2%	13.4%
720 day	Lab	11.5%	12.3%	11.6%	11.8%
	Field	13.5%	13.8%	13.0%	13.5%
	Core	13.2%	12.8%	12.4%	12.8%

Table C.11: Boil Test Data (% voids), Summer Slab, 65% PC/35% S

Age	Sample Type	Sample 1	Sample 2	Sample 3	Average
28 day	Lab	12.4%	12.1%	12.2%	12.2%
	Field	13.4%	13.4%	12.9%	13.2%
	Core	12.8%	13.0%	14.0%	13.3%
56 day	Lab	12.6%	12.3%	12.1%	12.3%
	Field	14.3%	13.7%	13.8%	13.9%
	Core	15.6%	13.0%	12.9%	13.9%
90 day	Lab	11.8%	11.7%	11.7%	11.8%
	Field	13.7%	12.9%	13.1%	13.2%
	Core	12.9%	13.0%	13.2%	13.0%
180 day	Lab	12.7%	12.7%	11.9%	12.4%
	Field	13.6%	13.7%	13.4%	13.5%
	Core	11.8%	12.3%	12.7%	12.3%
360 day	Lab	11.5%	11.4%	11.3%	11.4%
	Field	12.1%	12.3%	12.3%	12.2%
	Core	12.7%	12.5%	13.6%	13.0%
720 day	Lab	11.6%	11.7%	11.6%	11.6%
	Field	10.7%	10.5%	10.7%	10.6%
	Core	10.1%	9.5%	9.7%	9.8%

Table C.12: Boil Test Data (% voids), Summer Slab, 60% PC/25% S/15% FA

Age	Sample Type	Sample 1	Sample 2	Sample 3	Average
28 day	Lab	13.3%	12.6%	12.7%	12.9%
	Field	14.7%	14.8%	14.2%	14.6%
	Core	13.0%	13.5%	14.1%	13.6%
56 day	Lab	12.8%	13.2%	12.5%	12.8%
	Field	15.5%	14.9%	15.2%	15.2%
	Core	14.7%	13.6%	13.3%	13.9%
90 day	Lab	12.8%	12.7%	12.5%	12.6%
	Field	14.7%	14.3%	14.4%	14.5%
	Core	13.8%	14.1%	12.5%	13.5%
180 day	Lab	13.3%	13.2%	12.6%	13.0%
	Field	14.6%	14.6%	13.4%	14.2%
	Core	12.1%	12.2%	12.1%	12.1%
360 day	Lab	12.6%	12.5%	12.5%	12.5%
	Field	14.4%	13.0%	13.3%	13.6%
	Core	13.6%	13.0%	12.7%	13.1%
720 day	Lab	12.6%	12.9%	12.6%	12.7%
	Field	13.0%	13.2%	12.4%	12.9%
	Core	14.2%	12.9%	13.0%	13.4%

Table C.13: Boil Test Data (% voids), Fall Slab, 100% PC

Age	Sample Type	Sample 1	Sample 2	Sample 3	Average
28 day	Lab	12.5%	12.4%	12.3%	12.4%
	Field	13.5%	13.2%	12.9%	13.2%
	Core	12.5%	12.6%	13.7%	13.0%
56 day	Lab	12.0%	12.0%	11.7%	11.9%
	Field	12.5%	13.1%	13.2%	12.9%
	Core	11.9%	11.9%	12.3%	12.0%
90 day	Lab	12.0%	12.2%	11.7%	11.9%
	Field	12.7%	12.3%	12.8%	12.6%
	Core	12.4%	12.6%	12.7%	12.6%
180 day	Lab	12.4%	11.7%	11.6%	11.9%
	Field	12.0%	12.0%	12.9%	12.3%
	Core	11.8%	11.7%	14.5%	12.7%
360 day	Lab	12.0%	11.9%	11.2%	11.7%
	Field	12.3%	12.1%	11.9%	12.1%
	Core	11.7%	12.0%	11.7%	11.8%
720 day	Lab	11.8%	11.2%	10.7%	11.2%
	Field	12.2%	12.1%	11.9%	12.1%
	Core	13.5%	13.5%	12.8%	13.3%

Table C.14: Boil Test Data (% voids), Fall Slab, 65% PC/35% S

Age	Sample Type	Sample 1	Sample 2	Sample 3	Average
28 day	Lab	12.1%	11.7%	11.7%	11.8%
	Field	13.0%	12.7%	13.4%	13.0%
	Core	12.4%	12.2%	12.4%	12.3%
56 day	Lab	11.6%	11.4%	11.8%	11.6%
	Field	12.8%	13.4%	13.2%	13.1%
	Core	13.1%	12.5%	12.7%	12.8%
90 day	Lab	12.2%	11.5%	12.2%	12.0%
	Field	13.5%	12.1%	12.7%	12.7%
	Core	12.2%	12.6%	12.5%	12.4%
180 day	Lab	12.3%	11.7%	10.9%	11.7%
	Field	13.4%	13.3%	13.7%	13.5%
	Core	13.3%	12.7%	12.8%	12.9%
360 day	Lab	11.4%	12.1%	11.0%	11.5%
	Field	12.7%	12.0%	12.2%	12.3%
	Core	12.0%	12.1%	11.5%	11.9%
720 day	Lab	12.0%	11.1%	11.3%	11.5%
	Field	13.4%	12.0%	12.9%	12.8%
	Core	13.1%	11.6%	12.0%	12.2%

Table C.15: Boil Test Data (% voids), Fall Slab, 60% PC/25% S/15% FA

Age	Sample Type	Sample			Average
		1	2	3	
28 day	Lab	14.7%	14.7%	14.3%	14.6%
	Field	17.7%	17.8%	16.6%	17.3%
	Core	14.7%	15.1%	16.0%	15.3%
56 day	Lab	13.5%	14.6%	13.9%	14.0%
	Field	16.0%	16.0%	15.8%	15.9%
	Core	14.2%	15.1%	14.8%	14.7%
90 day	Lab	14.0%	14.2%	13.9%	14.1%
	Field	16.4%	16.8%	16.8%	16.7%
	Core	15.5%	11.7%	16.2%	14.4%
180 day	Lab	14.0%	13.8%	14.0%	13.9%
	Field	15.7%	15.0%	14.5%	15.1%
	Core	15.5%	15.2%	14.7%	15.1%
360 day	Lab	14.1%	13.7%	14.0%	13.9%
	Field	16.4%	15.9%	15.8%	16.0%
	Core	15.2%	15.6%	14.6%	15.1%
720 day	Lab	13.6%	13.9%	13.7%	13.7%
	Field	15.1%	15.3%	14.8%	15.1%
	Core	15.4%	15.5%	14.8%	15.3%

Table C.16: Boil Test Data (% voids), Spring Slab, 100% PC

Age	Sample Type	Sample 1	Sample 2	Sample 3	Average
28 day	Lab	11.2%	11.0%	11.1%	11.1%
	Field	12.5%	12.7%	11.5%	12.2%
	Core	11.8%	11.7%	11.1%	11.5%
56 day	Lab	10.5%	10.2%	10.2%	10.3%
	Field	10.6%	10.7%	10.8%	10.7%
	Core	10.5%	10.3%	10.4%	10.4%
90 day	Lab	9.7%	10.4%	10.2%	10.1%
	Field	11.2%	11.4%	10.4%	11.0%
	Core	10.2%	10.4%	10.1%	10.2%
180 day	Lab	10.1%	9.7%	10.3%	10.0%
	Field	11.4%	11.2%	10.5%	11.0%
	Core	10.3%	10.1%	10.1%	10.2%
360 day	Lab	10.7%	10.4%	10.6%	10.6%
	Field	11.8%	11.7%	11.3%	11.6%
	Core	11.0%	10.6%	10.7%	10.8%
720 day	Lab	10.0%	10.0%	9.3%	9.8%
	Field	10.4%	10.2%	9.9%	10.2%
	Core	9.8%	10.0%	9.7%	9.8%

Table C.17: Boil Test Data (% voids), Spring Slab, 65% PC/35% S

Age	Sample Type	Sample 1	Sample 2	Sample 3	Average
28 day	Lab	12.0%	11.3%	11.4%	11.6%
	Field	13.4%	13.6%	12.9%	13.3%
	Core	12.6%	12.8%	12.9%	12.8%
56 day	Lab	11.4%	11.6%	11.8%	11.6%
	Field	13.2%	12.8%	13.7%	13.2%
	Core	13.2%	13.5%	12.4%	13.0%
90 day	Lab	11.1%	10.8%	11.0%	11.0%
	Field	13.3%	12.0%	12.4%	12.6%
	Core	12.2%	13.5%	13.6%	13.1%
180 day	Lab	11.8%	11.7%	11.4%	11.6%
	Field	12.8%	13.4%	12.2%	12.8%
	Core	12.7%	12.2%	11.7%	12.2%
360 day	Lab	11.3%	11.9%	11.3%	11.5%
	Field	13.0%	12.9%	13.8%	13.2%
	Core	13.6%	12.9%	12.7%	13.1%
720 day	Lab	10.4%	10.7%	10.3%	10.5%
	Field	11.6%	11.7%	12.2%	11.8%
	Core	12.0%	12.1%	13.4%	12.5%

Table C.18: Boil Test Data (% voids), Spring Slab, 60% PC/25% S/15% FA

Age	Sample Type	Sample 1	Sample 2	Sample 3	Average
28 day	Lab	11.3%	11.5%	11.5%	11.4%
	Field	13.0%	12.2%	12.9%	12.7%
	Core	12.0%	11.7%	12.1%	11.9%
56 day	Lab	11.2%	11.8%	11.5%	11.5%
	Field	12.8%	12.6%	12.4%	12.6%
	Core	12.3%	11.6%	11.9%	11.9%
90 day	Lab	11.2%	11.2%	11.9%	11.5%
	Field	13.0%	13.2%	13.5%	13.2%
	Core	12.0%	13.4%	12.5%	12.6%
180 day	Lab	10.23%	10.3%	10.97%	10.5%
	Field	12.4%	12.7%	12.4%	12.5%
	Core	12.6%	10.6%	11.8%	11.7%
360 day	Lab	11.8%	11.9%	11.6%	11.7%
	Field	13.0%	13.1%	13.7%	13.3%
	Core	13.0%	13.7%	11.7%	12.8%
720 day	Lab	10.4%	10.7%	10.7%	10.6%
	Field	12.7%	13.4%	13.0%	13.0%
	Core	11.9%	11.5%	11.3%	11.6%

Table C.19: RCP Test Data (coulombs), Summer Slab, 100% PC

Age	Sample Type	Sample			Average
		1	2	3	
28 day	Lab	2533	2780	1719	2340
	Field	4026	4199	4127	4120
	Core	4065	4012	3522	3870
56 day	Lab	3028	2930	2777	2910
	Field	4661	5375	3182	4410
	Core	4426	3443	2444	3440
90 day	Lab	2403	2439	2747	2530
	Field	3850	4216	4158	4070
	Core	2061	3662	3163	2960
180 day	Lab	2233	1871	2197	2100
	Field	3543	4762	3775	4030
	Core	3990	4467	3408	3950
360 day	Lab	-	1854	2142	2000
	Field	3614	3311	3018	3310
	Core	5026	5019	4003	4680
720 day	Lab	1880	1952	1923	1920
	Field	2770	3610	3007	3130
	Core	4955	4664	4677	4770

Table C.20: RCP Test Data (coulombs), Summer Slab, 65% PC/35% S

Age	Sample Type	Sample 1	Sample 2	Sample 3	Average
28 day	Lab	1484	1486	1128	1370
	Field	2852	2774	2696	2770
	Core	2358	1487	1474	1770
56 day	Lab	1310	1467	1198	1330
	Field	1634	1979	2131	1880
	Core	1367	1487	1404	1420
90 day	Lab	1165	1186	1190	1180
	Field	1822	1783	1839	1810
	Core	1440	2144	2431	2010
180 day	Lab	1193	1223	1100	1170
	Field	1279	1194	1223	1230
	Core	1054	981	1360	1130
360 day	Lab	795	778	795	790
	Field	1167	1194	1165	1180
	Core	815	1237	757	940
720 day	Lab	526	867	774	720
	Field	1210	1138	1090	1150
	Core	1090	1748	1552	1460

Table C.21: RCP Test Data (coulombs), Summer Slab, 60% PC/25% S/15% FA

Age	Sample Type	Sample			Average
		1	2	3	
28 day	Lab	1657	1767	1251	1560
	Field	3145	4063	3115	3440
	Core	1506	1830	1434	1590
56 day	Lab	1078	1356	1364	1270
	Field	2791	2643	2431	2620
	Core	1332	1675	1616	1540
90 day	Lab	1293	1513	1466	1420
	Field	2594	2435	2117	2380
	Core	1622	1925	1515	1690
180 day	Lab	959	1053	1306	1110
	Field	1892	1616	1550	1690
	Core	1594	1558	1458	1540
360 day	Lab	888	829	729	820
	Field	1542	1278	1024	1280
	Core	1127	863	853	950
720 day	Lab	724	792	717	740
	Field	1016	1097	1343	1150
	Core	1156	1036	911	1030

Table C.22: RCP Test Data (coulombs), Fall Slab, 100% PC

Age	Sample Type	Sample 1	Sample 2	Sample 3	Average
28 day	Lab	2965	3865	3926	3590
	Field	4504	5523	5353	5130
	Core	4681	4521	4623	4610
56 day	Lab	2922	3156	3145	3070
	Field	3805	4489	4358	4220
	Core	4025	4063	4262	4120
90 day	Lab	2287	2413	2411	2370
	Field	3324	3599	3026	3320
	Core	4599	4587	4304	4500
180 day	Lab	2641	2490	2267	2470
	Field	3071	3327	2982	3130
	Core	3687	3630	3302	3540
360 day	Lab	1876	1905	2003	1930
	Field	2695	2875	3237	2940
	Core	3055	2693	2629	2790
720 day	Lab	1818	1977	1771	1860
	Field	2487	2793	2946	2740
	Core	2856	2678	2087	2540

Table C.23: RCP Test Data (coulombs), Fall Slab, 65% PC/35% S

Age	Sample Type	Sample 1	Sample 2	Sample 3	Average
28 day	Lab	1744	1714	1753	1740
	Field	2992	3203	2618	2940
	Core	1924	1994	2058	1990
56 day	Lab	1342	1321	1199	1290
	Field	1273	1388	1557	1410
	Core	1634	1503	1500	1550
90 day	Lab	1284	1185	1079	1180
	Field	1397	1488	1684	1520
	Core	1643	1668	1697	1670
180 day	Lab	743	810	797	780
	Field	911	911	1037	950
	Core	1064	1019	1025	1040
360 day	Lab	813	761	748	770
	Field	1294	1049	998	1110
	Core	797	744	701	750
720 day	Lab	651	638	664	650
	Field	764	943	1105	940
	Core	578	587	625	600

Table C.24: RCP Test Data (coulombs), Fall Slab, 60% PC/25% S/15% FA

Age	Sample Type	Sample 1	Sample 2	Sample 3	Average
28 day	Lab	2322	2585	2482	2460
	Field	4025	4471	3842	4110
	Core	3725	3724	3679	3710
56 day	Lab	1847	1667	1871	1800
	Field	3817	3425	3240	3490
	Core	3246	3477	3930	3550
90 day	Lab	1726	1455	1493	1560
	Field	2957	3212	2841	3000
	Core	2645	2841	2600	2700
180 day	Lab	990	972	1033	1000
	Field	2305	1858	1996	2050
	Core	1461	1332	1466	1420
360 day	Lab	936	918	925	930
	Field	1881	1885	1997	1920
	Core	1480	1109	1081	1220
720 day	Lab	733	855	838	810
	Field	1395	1419	1361	1390
	Core	980	1141	1047	1060

Table C.25: RCP Test Data (coulombs), Spring Slab, 100% PC

Age	Sample Type	Sample			Average
		1	2	3	
28 day	Lab	2797	2969	-	2880
	Field	3541	4260	-	3900
	Core	2713	2829	2642	2730
56 day	Lab	2065	1985	2067	2040
	Field	2644	2207	2281	2380
	Core	1978	1802	1437	1740
90 day	Lab	1890	1785	1963	1880
	Field	2685	2454	2476	2540
	Core	1980	1893	1678	1850
180 day	Lab	1659	1716	1721	1700
	Field	2584	2529	2563	2560
	Core	1570	1745	1761	1690
360 day	Lab	1607	1472	1320	1470
	Field	2355	2151	2293	2270
	Core	1659	1838	1567	1690
720 day	Lab	1330	1429	1164	1310
	Field	1878	1818	1724	1810
	Core	1018	1966	1515	1500

Table C.26: RCP Test Data (coulombs), Spring Slab, 65% PC/35% S

Age	Sample Type	Sample 1	Sample 2	Sample 3	Average
28 day	Lab	1596	1600	1556	1580
	Field	2677	2744	2648	2690
	Core	2500	2101	2086	2230
56 day	Lab	1029	1078	1034	1050
	Field	1523	1852	1862	1690
	Core	1243	1710	1510	1490
90 day	Lab	1052	1080	1105	1080
	Field	1855	1588	1746	1730
	Core	860	1469	1095	1140
180 day	Lab	919	973	812	900
	Field	1470	1435	1520	1480
	Core	907	1081	1223	1070
360 day	Lab	992	1003	824	940
	Field	1699	1877	1491	1690
	Core	1490	1792	1303	1530
720 day	Lab	650	732	652	680
	Field	1085	1203	1015	1100
	Core	988	1147	1071	1070

Table C.27: RCP Test Data (coulombs), Spring Slab, 60% PC/25% S/15% FA

Age	**Sample Type**	**Sample 1**	**Sample 2**	**Sample 3**	**Average**
28 day	Lab	1437	1664	1696	1600
	Field	1712	2229	2101	2010
	Core	2244	1797	1176	1740
56 day	Lab	1194	1243	1074	1170
	Field	2057	1632	1735	1810
	Core	1368	1259	1190	1270
90 day	Lab	1078	1122	1227	1140
	Field	1832	1158	1674	1550
	Core	1234	1077	1249	1190
180 day	Lab	866	843	985	900
	Field	1404	1490	1523	1470
	Core	1014	802	1407	1070
360 day	Lab	790	881	812	830
	Field	1301	1216	1152	1220
	Core	1559	1429	1034	1340
720 day	Lab	645	577	642	620
	Field	886	1044	927	950
	Core	645	666	801	700

APPENDIX D: Chloride Data for Lab Permeability Specimens

Table D.1: Strength Test Data (psi), Lab Permeability Specimens

Age	Mix	Sample			Average
		1	2	3	
28 day	9.15% air	4780	4410	4460	4550
	7.65% air	4770	5020	4750	4850
	5.9% air	5190	5190	5150	5180
56 day	9.15% air	5040	4280	4220	4510
	7.65% air	5070	5250	5450	5260
	5.9% air	5100	5110	4830	5010
90 day	9.15% air	4560	4340	4690	4530
	7.65% air	5920	6630	5510	6020
	5.9% air	6100	6410	6570	6360

Table D.2: Boil Test Data (% voids), Lab Permeability Specimens

Age	Mix	Sample			Average
		1	2	3	
28 day	9.15% air	11.7%	12.0%	11.6%	11.7%
	7.65% air	11.3%	11.9%	11.6%	11.6%
	5.9% air	11.4%	11.7%	11.2%	11.5%
56 day	9.15% air	11.7%	12.0%	11.8%	11.8%
	7.65% air	11.9%	11.5%	11.7%	11.7%
	5.9% air	11.3%	11.5%	11.1%	11.3%
90 day	9.15% air	11.4%	11.4%	11.3%	11.4%
	7.65% air	12.0%	11.4%	12.0%	11.8%
	5.9% air	11.1%	10.9%	11.1%	11.0%

Table D.3: RCP Test Data (coulombs), Lab Permeability Specimens

Age	Mix	Sample			Average
		1	2	3	
28 day	9.15% air	3750	3417	3143	3440
	7.65% air	2863	2627	2644	2710
	5.9% air	2909	2373	2398	2560
56 day	9.15% air	2562	2973	2520	2690
	7.65% air	2320	2294	2246	2290
	5.9% air	2209	1950	2326	2160
90 day	9.15% air	2472	2263	2050	2260
	7.65% air	1883	2103	2064	2020
	5.9% air	1960	1897	1715	1860

Table D.4: Chloride Concentration (lb/yd^3) for Lab Permeability Specimens with a 28-day Cure

Specimen	Depth of Sample (in.)				
9.15% air-1	**0.04-0.10**	**0.2-0.3**	**0.4-0.5**	**0.6-0.8**	**0.8-1.0**
A	13.12	5.24	2.52	0.63	0.38
B	8.96	5.17	2.52	0.88	0.82
C	10.22	6.25	3.15	0.95	0.44
7.65% air-1					
A	11.92	7.44	3.79	1.07	0.38
B	9.34	6.93	2.90	1.83	0.57
C	9.59	5.99	2.65	0.69	0.44
5.9% air-1					
A	9.21	6.88	2.71	0.50	0.57
B	11.37	7.07	4.35	1.64	0.82
C	9.02	5.49	1.51	0.63	0.50
9.15% air-4					
A	9.59	6.06	2.65	0.88	0.63
B	8.83	4.98	2.14	0.95	0.63
C	9.59	6.43	2.90	0.57	0.38
7.65% air-4					
A	10.35	5.55	2.59	0.63	0.32
B	-	-	-	-	-
C	8.71	5.93	2.97	1.01	0.50
5.9% air-4					
A	9.15	6.25	2.59	0.63	0.57
B	9.78	7.44	3.41	0.82	0.69
C	9.84	6.81	2.78	0.63	0.44
9.15% air-7					
A	8.89	6.18	2.40	0.69	0.50
B	8.64	4.35	2.90	0.63	0.25
C	9.20	4.42	3.79	2.02	1.14
7.65% air-7					
A	10.54	5.74	3.41	0.88	0.50
B	10.41	5.80	2.97	0.82	0.50
C	10.01	5.29	3.28	1.70	0.95
5.9% air-7					
A	9.08	4.86	2.52	0.63	0.44
B	9.64	8.83	4.35	1.45	1.51
C	8.61	5.87	2.97	0.63	0.44

Table D.5: Chloride Concentration (lb/yd^3) for Lab Permeability Specimens with a 56-day Cure

Specimen	**Depth of Sample (in.)**				
9.15% air-2	**0.04-0.10**	**0.2-0.3**	**0.4-0.5**	**0.6-0.8**	**0.8-1.0**
A	12.11	5.24	3.03	0.76	0.38
B	10.98	5.74	3.47	1.07	0.63
C	10.09	5.74	3.34	0.82	0.57
7.65% air-2					
A	10.54	6.56	2.90	0.82	0.63
B	10.03	5.80	3.03	0.76	0.57
C	13.12	6.94	3.28	1.01	0.57
5.9% air-2					
A	8.39	5.80	3.53	0.82	0.57
B	9.02	5.49	2.65	0.57	0.44
C	9.78	7.19	4.04	1.14	1.01
9.15% air-5					
A	10.41	6.25	3.97	0.88	0.50
B	11.73	5.93	3.03	1.07	0.44
C	11.54	6.37	3.79	1.20	0.76
7.65% air-5					
A	9.21	6.50	2.52	0.50	0.50
B	9.95	6.12	2.71	0.63	0.50
C	8.01	6.25	0.82	2.46	1.49
5.9% air-5					
A	10.79	6.81	3.41	0.63	0.50
B	9.97	5.87	1.77	0.63	0.50
C	9.27	6.18	2.14	0.88	0.57
9.15% air-8					
A	9.41	4.73	2.52	0.82	0.69
B	9.08	4.61	2.46	0.76	0.50
C	8.99	6.06	3.09	0.82	0.50
7.65% air-8					
A	9.02	6.56	3.03	0.88	0.50
B	11.23	5.11	1.64	0.63	0.50
C	10.28	6.56	3.09	0.95	0.82
5.9% air-8					
A	9.34	5.05	1.58	0.76	0.50
B	8.64	5.11	2.46	0.44	0.44
C	7.82	5.61	3.09	0.88	0.57

Table D.6: Chloride Concentration (lb/yd^3) for Lab Permeability Specimens with a 90-day Cure

Specimen	Depth of Sample (in.)				
9.15% air-3	**0.04-0.10**	**0.2-0.3**	**0.4-0.5**	**0.6-0.8**	**0.8-1.0**
A	7.82	4.26	3.44	1.20	0.69
B	8.39	5.11	2.08	0.69	0.57
C	8.64	5.05	2.14	0.82	0.63
7.65% air-3					
A	13.06	7.38	4.10	2.08	1.39
B	11.29	5.05	2.27	0.76	0.57
C	10.41	5.87	2.52	0.76	0.76
5.9% air-3					
A	7.63	5.36	2.14	1.01	1.14
B	8.25	5.24	1.96	0.82	0.69
C	7.07	4.61	2.14	0.69	0.63
9.15% air-6					
A	9.34	5.24	2.59	0.88	0.57
B	9.60	4.73	1.96	0.69	0.63
C	10.09	4.61	2.71	0.88	0.69
7.65% air-6					
A	9.53	5.80	2.90	1.07	0.57
B	10.03	5.36	2.52	0.63	0.44
C	9.78	4.98	2.58	0.88	0.76
5.9% air-6					
A	10.72	6.75	3.79	0.95	0.50
B	7.47	4.48	1.77	0.82	0.69
C	10.54	6.37	2.59	0.95	0.63
9.15% air-9					
A	10.54	5.24	2.46	0.76	0.63
B	7.87	4.61	3.09	1.26	0.69
C	9.27	5.36	2.65	0.88	0.50
7.65% air-9					
A	9.16	4.48	1.96	0.69	0.63
B	8.34	5.24	2.59	0.63	0.57
C	9.40	6.81	3.72	0.95	0.63
5.9% air-9					
A	6.37	4.61	1.77	0.82	0.76
B	6.31	4.42	1.77	0.57	0.50
C	8.17	4.35	1.89	0.63	0.63